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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 652

(Revision of Department Bulletin 71)

Contribution from the Office of Public Roads and Rural Engineering
LOGAN WALLER PAGE, Director

Washington, D. C. PROFESSIONAL PAPER June 6, 1918

THE WET LANDS OF SOUTHERN LOUISIANA AND THEIR DRAINAGE

By

CHARLES W. OKEY

Senior Drainage Engineer

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

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INTRODUCTION.

Louisiana ranks second among the States in the area of swamp land within its borders and in the percentage of its total area that is classed as swamp land. Of a total area of 45,420 square miles, 15,930 square miles, or 35 per cent, are classed as swamp and overflowed land. The drainage of these lands is a public improvement of very great importance to the future wealth and prosperity of the State. Although the magnitude of the task has long been recognized and the tremendous advantage that the reclamation of these lands would bring to the State has been generally admitted, it is but recently that the work of putting the swamp land into condition for cultivation has been attempted on any large scale. A number of conditions are responsible for this delay in the work, among which the following are important:

First, a very large proportion of the swamp lands of the State at one time was subject to overflow by the Mississippi River. The first step in the drainage of these lands was to protect them from river overflow by levees constructed along the main river channels. This phase of the work has been going on in some parts of the State for more than 100 years, and in nearly

all parts of the overflowed section since about 1875. It has been carried forward as fast as funds could be secured for the work. Second, the former abundance of cheap and well-drained agricultural land in this and other parts of the country made these lands unattractive. Third, the necessary State laws were not enacted until recently.

As the above-mentioned obstacles have been removed in a measure, the work of swamp-land drainage is attracting serious and widespread attention. The most active field of drainage operations at present is in the southern portion of the State, and it is there that the Department of Agriculture has been carrying on drainage investigations for about eleven years. The purpose of this work has been: (1) To study the soil, climate, and other natural conditions with special reference to the drainage problems encountered and the value of the land for agricultural purposes when successfully drained. (2) To collect such technical data and to examine such details of present practice as will afford information of value to landowners, and especially to engineers interested in the reclamation of such lands. (3) To disseminate the results of the investigations and to encourage land drainage by emphasizing the benefits to be derived from bringing such lands under cultivation.

Reports of results obtained have been made at frequent intervals, and partial reports have been published as often as seemed advisable. It is the purpose in this bulletin to include all salient features of the information so far published and to give also the results of later investigations. Where direct quotations from earlier publications are made, credit is given, but much of the material contained in the earlier publications and reports is so interwoven with later and more complete information that no specific mention is made of its source. The scope of this bulletin is as follows:

First, a description of general conditions in this section of the State, of such a nature and in such detail that persons unfamiliar with this or similar sections of the country will be able to form a fairly accurate idea of the nature of the problems encountered in the successful drainage and clutivation of these swamp lands.

Second, the results of detailed examinations of four drainage districts, reclaimed or in process of reclamation, and a summary of such results.

Third, a consideration of the problems involved in land drainage by means of pumps in Louisiana. This discus[illegible]ight be considered as a continuation of another bulletin published by t[illegible]dealing with pumping in the upper Mississippi River Valley.[1]

LOCATION AND GEN[illegible]L CONDITIONS.

As shown by figure 1, the area under consideration lies on the immediate Gulf coast. A range of hills running eastward from Baton Rouge, the State capital, to Lake Pontchartrain, forms, with the lake, the northern boundary of the portion lying east of the Mississippi River. Most of the land in this area is from 1 to 3 feet above sea level, with a very small percentage lying along the river and the larger bayous having an elevation of from 4 to 15 feet. To the westward, between the Mississippi and the Atchafalaya, the land rises gradually from sea level along the Gulf to an elevation of perhaps 15 or 20 feet along a line drawn from Baton Rouge to Lafayette, except in the immediate vicinity of the Atchafalaya River, where it is very little above sea

[1] U. S. Dept. Agr., Office Public Roads and Rural Engineering, Bulletin 304.

NOTE.—This revision of Department Bulletin 71 contains information of value to landowners, engineers, and others interested in drainage by pumping, especially of the wet prairies along the Gulf coast.

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FIG. 1. MAP OF SOUTHERN LOUISIANA SHOWING RECLAMATION DISTRICTS AND STORM TIDE DATA

level. In this section, as in the area to the east of the Mississippi River, there is a small percentage of higher land along the rivers and bayous. To the westward of the Atchafalaya River there is a strip of swamp land bordering the coast line which rises gradually from sea level to approximately 10 or 15 feet above at a distance of 20 or 30 miles inland.

The area of the district is about 12,000 square miles, of which about 10 per cent is high enough to be drained by gravity, this representing the percentage of the total area that already is drained and under cultivation. The remainder is so low that artificial means must be used to get an outlet for drainage water. The area shown in figure 1 is about one-fourth that of the entire State, yet the tract contains nearly two-thirds of the State's swamp land.

Throughout the entire district are connecting lakes and bayous, many of which are navigable by boats of considerable draft. The total length of such navigable streams is, roughly, 1,600 miles. The main waterway is the Mississippi River. The Atchafalaya River lately has been opened to deep-water navigation through a dredged channel at its mouth, and vessels of a draft of not more than 20 feet can enter it safely. This system of waterways insures excellent water transportation to the entire district, in addition to the facilities afforded by a number of railroads which traverse the district.

Besides the cities of New Orleans and Baton Rouge, there are several towns in the district, including Morgan City, Houma, Donaldsonville, New Iberia, Lafayette, Crowley, and Lake Charles, the principal railroad center of the western part of the State.

The very small percentage of this area that is under cultivation is worked very intensively and supports a population exceeding 200 to the square mile over the whole area. While the principal industry of the whole region is agriculture, the wealth derived from other sources, including sea food, lumber, oil, gas, salt, and sulphur, is almost as great.

CLIMATE.

Temperature.

In Bulletin W of the United States Weather Bureau the following statement is made:

Climatic conditions over southern Louisiana are marine in character; the proximity of the Gulf of Mexico and the numerous streams and lakes of this region all conspire to modify the temperature conditions and prevent sudden changes therein, and extremely warm weather in summer and severe cold weather in winter seldom occur.

For further information in regard to temperature see above-mentioned publication.

Rainfall.

The Weather Bureau summary of the climatological data for section 45 says of the yearly rainfall:

There is a gradual and well-defined decrease in precipitation from the eastern toward the western portion of this section. The average annual precipitation is 55.76 inches, and ranges from 48.36 inches at Lakeside, Cameron Parish, to 63.02 inches at Amite, Tangipahoa Parish. The precipitation is practically all in the form of rain and is well distributed throughout the year. Snow occurs on an average of once in three to five years, and disappears soon after having fallen. Although droughts occur, they are seldom long continued,

Note.—Acknowledgment is made of the helpful spirit of cooperation displayed by railroads, companies installing drainage systems, landowners, and practicing engineers in extending the scope and increasing the accuracy of this work.

and are not so serious as in regions where the level of the ground water is so much farther below the surface of the earth. June and July are usually the wettest, and October and November the driest months. Rain falls about once in three days. The average number of rainy days is 108 in the eastern and from 77 to 80 in the western portion of this section.

The following rainfall data are taken from the Weather Bureau records:

Mean monthly and annual rainfall, in inches, at Cameron, New Orleans, and Houma, La.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Cameron	3.71	3.29	3.23	3.23	3.70	5.76	7.70	3.98	5.32	2.94	3.91	3.36	50.13
New Orleans	4.63	4.57	5.30	4.91	3.88	6.16	6.47	5.61	4.81	2.93	3.79	4.46	57.52
Houma	3.45	4.77	3.45	4.12	3.58	5.91	9.23	6.35	5.92	3.04	2.68	4.31	56.81

The rainfall in this section is more or less tropical in character, especially in the summer months. The rains nearly always are purely local in the summer, and the amount, both daily and monthly, may vary greatly for stations separated by only a few miles. Thus we have a monthly total in August, 1911, of 28.5 inches at Donaldsonville, at the northern edge of this section, and but 12.27 inches at Houma, only about 40 miles away. The following table, compiled from the daily rainfall records of the United States Weather Bureau at New Orleans, from 1871 to 1916, gives the average number of storms per year of given intensities:

Average yearly number of storms of given intensities.

(Based on daily rainfall records of the U. S. Weather Bureau for New Orleans, La., 1871 to 1916, inclusive.)

Total rainfall.	Average number of storms per year.														
	1-day period.	2-day period.	3-day period.	4-day period.	5-day period.	6-day period.	7-day period.	8-day period.	9-day period.	10-day period.	11-day period.	12-day period.	13-day period.	14-day period.	15-day period.
3 inches.	1.652	2.998	3.972	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4 inches.	.673	1.372	1.828	2.172	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5 inches.	.326	.674	.847	1.021	1.130	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6 inches.	.196	.369	.456	.630	.762	0.848	.....	.....	.....	.....	.....	.....	.....	.....	.....
7 inches.	.153	.217	.304	.345	.391	.479	0.587	.....	.....	.....	.....	.....	.....	.....	.....
8 inches.	.109	.153	.153	.217	.283	.283	.326	0.270	.....	.....	.....	.....	.....	.....	.....
9 inches.	.022	.065	.087	.109	.153	.196	.196	.240	0.304	.....	.....	.....	.....	.....	.....
10 inches	.....	.....	.043	.065	.109	.153	.196	.196	.240	0.261	.....	.....	.....	.....	.....
11 inches	.....	.....	.022	.043	.065	.065	.087	.130	.130	.174	0.196	.....	.....	.....	.....
12 inches	.....	.....	.....	.....	.043	.065	.087	.087	.087	.087	.087	0.109	.....	.....	.....
13 inches	.....	.....	.....	.....	.....	.022	.043	.043	.043	.043	.043	.043	0.087	.....	.....
14 inches	.....	.....	.....	.....	.....	.022	.022	.022	.022	.022	.022	.022	.065	0.065	.....
15 inches	.....	.....	.....	.....	.....	.022	.022	.022	.022	.022	.022	.022	.043	.043	0.043

HEALTH CONDITIONS.

Of the healthfulness of this climate the Bureau of Soils says:[1]

A most serious check to the attraction of a desirable class of immigrants to this section is the impression which has gotten abroad as to its unhealthfulness. That this idea had some foundation in the past can not be denied, but such a condemnation can not now be applied to the State as a whole or to this particular vicinity. The records of the medical board of New Orleans show that the city has an excellent health record for a city of its size. * * *

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, pp. 443, 444.

Outside of the city sanitary conditions are naturally much better. The dwellings of both owners and the tenants of the plantations stand on the higher land along the Mississippi River, where there is adequate natural drainage. Notwithstanding the proximity of the swamps and standing water, malaria, though occasionally occurring, is not dreaded. Until within the last few years epidemics of yellow fever caused frequent alarm, but this disease has now been thoroughly eradicated, and with the methods of treating the disease and preventing its spread it is not to be dreaded as formerly, even if it should again appear.

Since it has been demonstrated that malaria, like yellow fever, can be transmitted to man only through the bite of a certain species of mosquito, it may be expected that drainage, which destroys the breeding places of these pests, will result in a decrease in whatever malaria now may exist. As a matter of fact, malarial fever is very rare on the immediate coast line, and the health of people who come from other sections seems to be fully as good as that of those born there.

SOILS.

The area under discussion contains soils that are peculiar to the section, and these now are being drained and cultivated for the first time. In the following section are set forth the results of first-hand investigations, along with the classification and general descriptive matter taken from publications of the United States Bureau of Soils.

Area East of the Atchafalaya River.

ORIGIN AND FORMATION OF SOILS.

The soil of the area east of the Atchafalaya River and in parts of St. Mary, Iberia, and St. Martin Parishes is of alluvial origin and is largely the result of deposits made by the Mississippi River and its branches. It has been built up from a depth of several thousand feet to the present elevation above the Gulf. In the very newest portions of the Delta at Port Eads, at the mouth of the river, a considerable subsidence of the land still is going on, the measured rate being about 0.11 foot per year. That this subsidence is due to a compacting of the newer deposits is shown by the fact that permanent bench marks along the Mississippi River record a decreasing settlement as the distance from the mouth of the river increases. Except in this relatively small area near the mouth of the river, the remainder of this section of the State shows no change in elevation. As is typical of delta regions, ridges of sandy soil are found along the main river channel and along its branching outlets. The manner in which these ridges were formed is well brought out in the following from "A Preliminary Report upon the Bluff and Mississippi Alluvial Lands of Louisiana," by W. W. Clendenin.[1]

[1] Louisiana Stas. Rpt. Geology and Agriculture, Pt. IV, p. 263.

With every flood the river now overflows its flood plain and deposits much of the sediment from its headwaters. As with a slight increase in velocity the transporting power is vastly increased, so with a slight checking of velocity, as occurs over the flood plain outside of channel, deposit takes place. As the greatest decrease in velocity takes place near the channel, there the heaviest and coarsest sediment is deposited, and in greatest quantity. The river banks are thus built higher by each flood and a system of natural levees is produced. There is thus a marked difference in the "front lands" and the "back lands" along the river. The former are higher and coarser textured than the latter, and therefore much more easily cultivated and drained.

Drainage from the very channel margin is away from the river, and unless forced by the topography of the land, will not reach the river proper, but unite with some outlet of the river produced during some extraordinary flood

period and kept open by the escape of water during ordinary periodic flood stages. As the feeders of the river are called tributaries, these outlets have not inaptly been styled distributaries.

Since practically all land in the Delta region now is protected from overflow by levees along the Mississippi River, all building up of the low marshlands has been checked. However, at the mouth of the Mississippi River deposition of material is continually taking place.

Even before the construction of the artificial levee system, there was no raising of the general level of the marshes during periods of normal flow and probably little sedimentation of the river bed excepting at its mouth, the most of the material which was carried in suspension to the lower portion of the river being carried out and deposited in the Gulf. As the river rose, however, the waters constantly sought additional outlets through the various bayous of the Delta country. At times of extreme high water there was a general breaking over the banks of the river and its outlets. It is probable that the most of the building up of the lands above sea level has been done at such times.[1]

The above statements show that while the Mississippi River and its various distributaries are extending themselves continually through deposition at their mouths, it was only at times of overflow that the ridges along the channels were raised or widened. The peculiar branched nature of the Delta, with bodies of land extending fingerlike into the Gulf, with open spaces of water between, is also thus accounted for. As these ridges gradually widened they approached each other, thus forming lakes and bayous. Tidal action usually kept these ridges from inclosing the open water between them, and heavy and prevailing winds no doubt often would change their character and direction. It is reasonably certain that the large inland lakes, such as Lake Des Allemands and Lake Salvador, were inclosed in this manner.

The fact that the silt-bearing capacity of water is directly dependent upon the velocity is clearly demonstrated by observing the natural embankments formed by streams of various sizes. In the case of smaller streams, when the water overflows its force is soon spent and the silt is quickly deposited near the stream, forming narrow ridges with steep side slopes, while those formed by large streams are broad with slight slopes. Three typical examples showing this difference and the manner in which the land surface has been raised on the marshes are given in figure 2, A, B, and C.

The sections were taken as follows:

A—From the right bank of the Mississippi River across the Willswood plantation, about 10 miles above New Orleans. This section is about 2 miles long, and a part of the lands crossed have been under cultivation for a great many years, while those farthest from the river were reclaimed only 12 or 15 years ago. The lowering of the surface of the cultivated and drained fields due to the shrinkage of humus soils is here well illustrated. There are many examples of highlands having been built up for much greater distances from the river than this, but as such accretions are indirect, on account of being formed by a number of small bayous or temporarily contracted areas of overflow which assisted in maintaining the velocity, these have not been considered as being typical.

B—The right bank of Bayou Lafourche at Lockport, extending back through the village of Lockport and beyond to Lake Fields. Until 1903 Bayou Lafourche served as an overflow outlet for the Mississippi River, the opening at Donaldsonville not having been permanently closed until that year.

C—This is a very small bayou extending to about 4 miles west of Lockport. The abrupt rise of the ridge from the surrounding marshes is especially noticeable and is characteristic of smaller bayous.

[1] Manuscript report of A. M. Shaw.

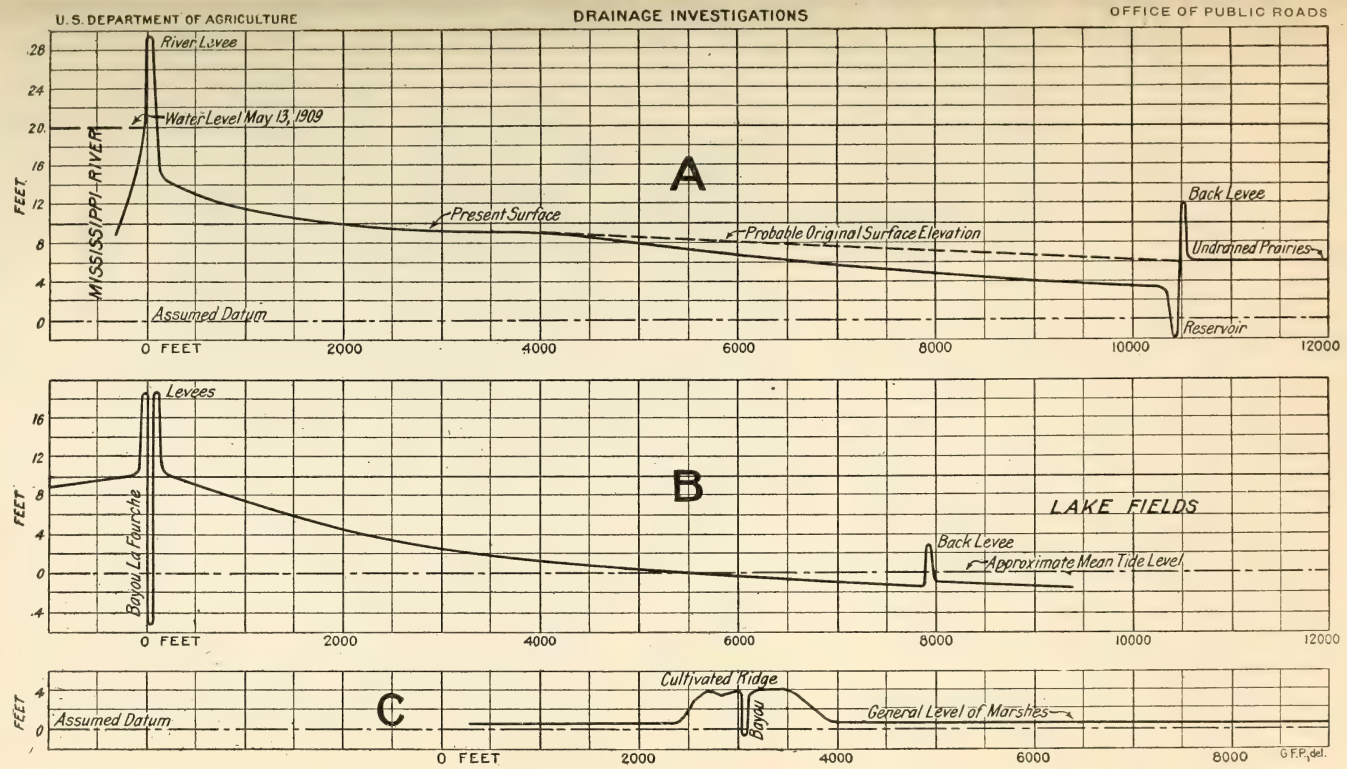

FIG. 2.—Typical examples of Louisiana marshland formation: A, Profile through Willswood Plantation; B, section through Smithport Plantation; C, formation caused by small bayou near Lockport.

Important exceptions to the foregoing general statement as to the relation between the size of bayous and the ridges built by them are frequently found. Prominent among those are the Bayou L'Ourse, in the southeastern part of Lafourche Parish, and the Wax and Little Wax Bayous, in St. Mary Parish. Bayou L'Ourse is an insignificant stream, occupying the center of a long and important ridge. It is probable that at one time this bayou served as an outlet for Lafourche, or possibly for some predecessor of the latter bayou for draining in a more easterly direction through Bayou Blue, Lake Fields, and Long Lake. Wax and Little Wax Bayous are streams of erosion rather than of sedimentation and have been formed wholly or in part by the action of storms and the tidal flow, which is quite strong along this portion of the coast. As a result, the bayous are bordered by the marsh or by very low ridges. Both streams are from 10 to 50 feet in depth and 100 to 200 feet in width.[1]

In addition to the above, Bayous Terrebonne and Black, in Terrebonne Parish, are typical examples of the sedimentation type; while Bayou des Allemands, the connection between Lake Des Allemands and Lake Salvador, is an excellent illustration of the tidal-erosion type.

From the foregoing it may be seen that the chief difference between the various types of soils is the variation in fineness of material rather than difference in chemical composition.

CLASSIFICATION AND EXTENT OF SOILS.

The various types of soils grade imperceptibly into each other, but the following classifications have been made by the Bureau of Soils: Yazoo sandy loam, Yazoo loam, Yazoo clay, Sharkey clay, muck, and Galveston clay. The first three are ridge soils and limited in extent; they form a very small percentage of the total area. These soils have sufficient elevation to drain by gravity, and as practically all are well drained and cultivated they will not be discussed further. The last three classes include practically all the undrained soils of this section. The Sharkey clay is a heavy alluvial soil. For the top 5 or 6 inches it is black, due to the heavy percentage of decayed vegetable matter; the subsoil is a brown or drab, waxy, very impervious clay. The soil shrinks greatly on drying, leaving large sun cracks. This, combined with the effect of the decayed vegetable matter, causes the soil to break up very readily under the plow. For the most part the Sharkey clay areas are heavily forested, the better-drained portions having a dense growth of hardwoods and the wettest portions being covered with cypress.

The muck and Galveston clay areas are practically the same. On top of the above-described Sharkey clay the decaying vegetation of the open grass-covered prairies has formed a mass of material which is quite variable in character. Where it is almost pure vegetable matter it is classed as muck or peaty muck, and where the percentage of silt or clay is rather heavy it is classed as Galveston clay. The depth of this layer of vegetable matter varies from a few inches to several feet. In its natural state it nearly always is covered with water and is very soft and boggy. For a further description of these soils see the publications of the Bureau of Soils.[2]

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[1] Manuscript report of A. M. Shaw.

[2] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, p. 451–453; also 1911.

Area West of the Atchafalaya River.

ORIGIN AND FORMATION OF SOILS.

Most of the land of this section consists of recent coastal plain deposits rather than of Mississippi River alluvium, and surface conditions are somewhat different from those encountered in the eastern or delta section of the State. Instead of a succession of ridges and shallow lakes, such as occur in the delta section, we have a costal plain rising gradually from south to north. Along the immediate coast line there is a more or less unbroken sandy ridge through which the rivers have cut channels. Immediately back of the ridges are stretches of salt marsh very little above sea level, but which rise gradually to the north, so that at a distance of some 5 to 10 miles inland they become fresh-water marsh. The larger streams, such as the Mermentau, the Calcasieu, and the Sabine, still deposit alluvium, and since the coast line was elevated these streams have extended considerably the land adjoining them. As the waters of these outlets are very sluggish and are not heavily loaded with silt, they have not built up large ridges along the immediate river banks. The alluvial portion is nearly level, and the strips of alluvial land along the channels widen gradually as the streams approach the Gulf. These alluvial strips still are in process of formation and of elevation by deposition, since at each high water the adjoining lands are flooded, the rivers not having been leveed.

CLASSIFICATION AND EXTENT OF SOILS.

The Bureau of Soils has not made surveys of this section, but has examined and classified the soils immediately north of it. The various clays, clay loams, silt loams, and sandy loams are described in detail in publications of that bureau.[1] Toward the Gulf the above-enumerated soils are overlain by muck and alluvial deposits and thus become subsoils.

The lands of this section might be divided into two main divisions, as indicated in the paragraph on origin and formation: (1) The general wet prairie land, with a comparatively shallow deposit of silt and muck on the surface; and (2) the strips of alluvial land along the river channels or streams. The first class includes the great bulk of the lands. As noted above, the subsoils of this portion are the solid loams, etc., of the higher land, thus affording a firm foundation quite different from the soft, yielding alluvial silt of the Mississippi Delta swamps. Overlying this subsoil occurs a shallow deposit of partly alluvial silt caused by local erosion and weathering. There is little or no muck on the surface of the higher and better-drained portions, although the silt of the top 6 inches is rich in vegetable matter due to the decay of the grasses. These portions are covered with water only during the rainy season, and in times of long drought ordinary wagons can be driven over them. Toward the south, however, the land is water covered practically all of the time, and a layer of muck has formed from decaying prairie grass. In its essential characteristics this muck is very similar to that of the Mississippi Delta section. It averages from 6 to 18 inches in thickness, although in low depressions and shallow bayous it may be several feet deep. Owing to the absence of any extensively silt-bearing streams, the muck of these wide level prairie sections is composed almost entirely of vegetable matter, and its dry weight is less than that of the average muck of the Delta section. This, however, should not be an undesirable feature, as most of it is so shallow that the cultivation soon will extend into the

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1901 and 1903.

silt below. As the coast line is approached, as noted before, the marsh becomes salt, but it is covered with practically the same depth of muck. In various places in this section there are broad zones where the silt deposit between the muck and the underlying subsoil is perhaps 3 or 4 feet deep and has a chocolate-brown color similar to that of the soil of the Sharkey clay regions. These areas are more numerous in the lower portions of the prairie.

Along the larger rivers, especially near their mouths, the alluvial belts of soil are quite wide. In these sections the rivers have laid down alluvium many feet in thickness on the older deposits. The building up of these flood plains has been very slow, and the marsh-grass growth has been continuous; thus we have near the top a muck with a high percentage of silt, grading down into a silt with a large percentage of vegetable material at a depth of from 1 to 4 feet. Parts of this alluvial section are soft, although the land immediately along the river channels sometimes is quite firm. The muck is similar to that of the Mississippi Delta section, except that the silt is well mixed with it instead of occurring in alternate layers.

DRAINAGE CHARACTERISTICS OF SOILS.

As the ultimate success of most of the reclamation districts of this section depends on the successful drainage and cultivation of the muck lands, a rather detailed study of them was made. In investigating these soils it was the endeavor to get a careful description of their physical characteristics, to find the percentage of water by volume that they would contain when in good condition for growing crops, and to ascertain the amount of water they would hold when completely saturated.

The muck is a mass of vegetation in varying stages of decay and contains varying amounts of river silt. It differs in character according to the kind of vegetation from which it was derived; thus the muck of the cypress swamp is much darker and less fibrous than the muck or turf of the open, grass-covered prairie. Also, according to stage of decay, it may be tough and fibrous and able to bear the weight of a man, or it may be soft and even semifluid if considerable water be present. Being the result of growth rather than of deposit, it has been formed in layers, the depth of which depends largely on the time involved. When a layer of vegetation is covered with a heavy layer of silt all addition to the former ceases, and if conditions be favorable a new layer of vegetation is formed on the silt above. Thus we have strata of muck varying in thickness from an inch to several feet, with intermediate strata of silt of depths of from 1 inch to perhaps 2 feet. About half of the waterways that extend through these swamps are streams of tidal erosion; along these streams the high ridges of river silt are absent, and the muck is specially deep. Bayou des Allemands, Wax Bayou, and Little Wax Bayou are streams of this character.

The samples of muck examined were taken at just sufficient depth below the surface to insure the optimum percentage of water—i. e., the amount of moisture considered by local plantation owners to be the best for the growth of general field crops. No samples were taken immediately after a rain or after a long dry period. At the time of taking the samples a description of each field was made, including depth of water table, length of time the field had been drained and cultivated, time since last rainfall, character of original vegetation, nature of present crop, and other conditions peculiar to the tract in question. The following tables show the results of tests made in the spring of 1910:

Results of soil tests on Lafourche drainage district No. 12, subdistrict No. 2, Raceland, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.			Water in soil by volume.			Depth of water table.
			Normal.	Saturated.	Dry.	Normal.	Saturated.	Gain.	
Turf:	*Inches.*		*Pounds.*	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*
12	4–10	7	45.8	61.5	7.0	62.1	87.2	25.1	18
13	4–10	7	54.4	.....	8.7	73.1	.....	.....	18
22	4–10	10	44.0	.....	9.4	55.4	.....	.....	20
23	4–10	10	45.8	62.3	12.4	53.4	79.8	26.4	20
24	5–10	10	43.9	.....	10.7	53.1	.....	.....	20
25	5–10	10	46.7	60.7	14.0	52.3	74.7	22.4	20
30	3– 8	14	41.3	61.5	7.6	53.0	86.2	32.3	20
31	3– 8	14	41.3	.....	7.9	53.4	.....	.....	20
32	6–10	14	51.2	.....	7.9	69.4	.....	.....	22
33	6–10	14	47.3	57.6	7.3	64.0	80.5	16.5	22
Turf with silt:									
10	8–12	7	57.9	71.3	21.2	58.7	80.5	21.4	20
11	8–12	7	61.4	.....	22.8	61.8	.....	.....	20
14	12–16	7	64.0	77.6	29.5	55.2	77.0	21.8	18
15	12–16	7	66.0	.....	30.0	57.5	.....	.....	18
16[1]	3– 7	7	53.7	67.9	14.9	62.0	84.8	22.8	20
17[1]	3– 7	7	56.2	.....	16.9	62.9	.....	.....	20
26[1]	3– 8	10	54.8	.....	16.9	60.6	.....	.....	24
27[1]	3– 8	10	46.7	64.9	8.7	60.8	89.9	29.1	24

[1] Turf and silt after being mixed by two years of cultivation.

The above samples were taken from the soil on subdistrict No. 2, which lies about 5 miles from Bayou Lafourche and the same distance from Raceland. This district is a part of the open, grass-covered prairie and had been well drained for about three years. Its elevation is perhaps a foot above mean tide level, and the soil probably would be classed as Galveston clay. The fields from which these samples were taken were in cultivation in 1909 and were planted to corn or sugar cane in the spring of 1910. The original vegetation was a wild prairie grass, locally called "paille fina." The muck or turf was formed from this grass. The soil of the top 4 to 5 inches was quite soft and dry, having been recently cultivated. Just below the depth of cultivation the soil became moist, and water would drip from it when compressed. The muck here was of a dark-brown color and very light and spongy; after drying it became much darker in color. It seemed to be a mass of partially decayed grass and grass roots and had very little, if any, silt in its composition. The depth of the muck on this tract varied from 6 to 18 inches. Below this came a layer of mixed turf and silt about 1 foot in thickness, and from there on down to a great depth occurred pure silt which would be classed as Sharkey clay. The ground-water level stood a little less than 2 feet below the surface, which is about the average depth of drainage secured on this tract. The first 10 samples in the table were taken from the layer of pure turf; the next four, Nos. 10, 11, 14, and 15, from the layer of mixed silt and vegetation just under the layer of pure turf; and the last four, Nos. 16, 17, 26, and 27, from a field on the same tract that had been cultivated for two years, but that had not been cultivated in 1910 when the samples were taken. The last four samples show the result of deep plowing, thus mixing the silt and the pure turf, and give an idea of the conditions that may be expected after the fields have been cultivated for a time.

The following table gives the results of tests of the muck on Lafourche Drainage District No. 12, subdistrict No. 3, which lies a little farther out from Bayou Lafourche than does subdistrict No. 2.

Results of soil tests on Lafourche drainage district No. 12, subdistrict No. 3, Raceland, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.			Water in soil by volume.			Depth of water table.
			Normal.	Saturated.	Dry.	Normal.	Saturated.	Gain.	
Muck:	*Inches.*		*Pounds.*	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*
28	4–9	10	48.9	.....	10.0	62.2	.....	.....	18
29	4–9	10	51.2	63.7	10.8	64.7	84.7	20.0	18
34[1]	3–8	14	59.2	.....	10.0	78.7	.....	.....	12
35[1]	3–8	14	58.2	63.8	10.2	76.8	85.8	9.0	12

[1] Samples 34 and 35 were undoubtedly too moist for optimum percentage of moisture.

The conditions on this area were similar to those on subdistrict No. 2, except that the land on the former had been well drained only eight months and had not been cultivated. The top of the muck was covered to a depth of about 4 inches with a tough sod full of heavy grass roots, but below this soil these roots tapered out to very fine rootlets. The samples contained pure turf which was very similar to samples 12 to 33, inclusive, of subdistrict No. 2.

The samples recorded in the following table were taken from Smithport Plantation, which lies about 1 mile back from Bayou Lafourche, near Lockport, La.

Results of soil tests on Smithport Plantation, Lockport, La.

No. of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.			Water in soil by volume.			Depth of water table.
			Normal.	Saturated.	Dry.	Normal.	Saturated.	Gain.	
Muck:	*Inches.*		*Pounds.*	*Pounds.*	*Pounds.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inches.*
18	10–15	4	54.4	.....	21.9	52.0	.....	.....	22
20	8–13	4	52.0	.....	13.4	61.8	.....	.....	22
40	7–12	14	52.9	73.0	14.0	62.2	94.4	32.2	26
42	8–13	14	52.0	61.5	10.7	66.1	81.3	15.2	22
Silt:									
19	3–7	4	112.0	.....	88.6	37.5	.....	.....	24
21	2–7	4	80.0	.....	48.3	50.7	.....	.....	24
41	2–7	14	74.8	85.6	47.0	44.5	61.8	17.3	26
43	3–7	14	111.5	.....	81.9	47.4	.....	.....	26

This tract was a part of the grass-covered prairie which contained a number of scattering groves of small willows. It had been cleared and drained for about five years. Its elevation above mean tide level is about 1 foot. The top soil is a layer of almost pure silt 6 to 10 inches thick which has been laid down on a layer of muck perhaps 12 inches thick at a comparatively recent date. Below this muck is a deposit of pure silt extending to a great depth. The turf or muck in this tract is perhaps older than that of subdistrict No. 2, Raceland; it seems to have been formed from the same kind of vegetation, but it is heavier and much darker than that of the latter district. This is due probably to the weight of the layer of silt which had been deposited on it. The ground had been cultivated in 1910, and the part moved by cultivation was quite hard and dry; however, this cultivation did not reach below the layer of silt, into the muck. The first four samples were taken from the layer of muck, while the next four were taken from the silt overlying the muck. Both layers of soil were tested so as to get an idea of

the combined water capacity of the two varieties, for many of the plantations have a mixed soil much like that of the Smithport Plantation.

The samples recorded in the following table were taken in Bayou Lafourche sandy loam near Lockport and about one-fourth mile back from the bayou.

Results of soil tests near Lockport, La.

Number of sample.	Depth of sample.	Number of days since rain.	Weight per cubic foot.		Water in soil by volume.	Depth of water table.
			As taken.	Dry.		
Sandy loam:	*Inches.*		*Pounds.*	*Pounds.*	*Per cent.*	*Inches.*
36	3–8	14	105.9	81.2	39.5	40
37	3–8	14	105.4	80.6	39.7	40
38	6–11	14	105.9	75.4	48.8	40
39	6–11	14	105.4	78.1	43.7	40

The soil in this tract is representative of the average soil conditions in the bayou-front plantations. It also is of much the same nature as the ridges of silt that occur in many of the turf or muck lands. The soil had been cultivated for a great many years, and little vegetable matter was present. It already had been cultivated in 1910 when the samples were taken. The ground was quite moist to the touch, but was perhaps a little drier than usual. The soil was much the same to a very great depth. The tests were made for the purpose of comparison with the tests of the muck.

It will be noted by comparing samples 40 and 42, in the summary of results of soil tests on the Smithport plantation, with samples 36 to 39, inclusive, taken near Lockport, that the muck soil seems to be more retentive of moisture than the sandy loam of the bayou ridge. The samples of each class of soil were taken at approximately the same depth and on the same date, yet the muck contained nearly 50 per cent more water than the sandy loam. Later in this same season, which was unusually dry, the crops on the muck soil withstood the effects of the drought better than did those on the sandy ridge soil.

In general, the layers of turf or muck of southern Louisiana having been formed on an alluvial deposit, and in many cases mixed with silt, the turf after a few years of cultivation works up into a most excellent soil which is well balanced in chemical composition. This is proved by the excellent yields of both truck and general field crops on such lands near Lockport and Raceland. The muck of the cultivated fields has a greater density and a darker color than that where the land is undrained and uncultivated. In its original state the pure turf is a light brown, but as it dries and decays it becomes darker and finally is almost black. When first drained it is very light and spongy and when plowed breaks up into rather large pieces, sometimes as much as a foot square, which are pushed ahead of the plow instead of being turned in a furrow. After the second year of cultivation the muck loses its fibrous nature and resembles old sawdust in texture, although a little darker in color. As cultivation continues the muck mixes more and more with the underlying silt, and a much heavier and more impervious soil results.

SUBSIDENCE OF SOILS.

It is well known that swamp lands having soils containing a large percentage of vegetable matter subside when drained and cultivated. This subsidence is due to three main causes—drying, decay, and cultivation. Shrinkage and the consequent subsidence, due to drying, affects mostly the top layer but ex-

tends in a decreasing degree as deep as the soil is drained. Tests have shown that undrained Louisiana muck shrinks about 60 per cent in volume when completely dry, and that it will regain only 70 per cent of its original volume when saturated for a long time. Therefore long-continued dry weather and deep drainage cause a shrinkage in the deeper layers of muck which is not fully offset by any increase in volume which occurs after subsequent precipitation or rising of the water table. Only such part of the muck as is always saturated is entirely free from shrinkage due to drying.

The vegetable material in muck soils exists in a state of partial decay. In the undrained state it is so saturated with water that the process of decay is relatively slow. After drainage the air enters, and decay is much more rapid. The warm, humid climate of southern Louisiana is very favorable to the rapid decay of vegetable material, much more so than are those sections where the surface is frozen for a part of the year. Like the effect of drying, that of decay is greatest in the top layer of material, but examination has shown that after some years of drainage the character of the muck at a depth of 2 feet is materially changed. While the effect of decay is not as rapid in action as that of drying, it is practically continuous. The complete decay of the vegetable matter causes some loss of weight and considerable loss in volume, thus gradually reducing the surface elevation of the muck.

As the effects of both the foregoing agencies are greatest in the top layer of the muck, the density of this layer is gradually increased. After this comparatively dense material attains a thickness of a few inches it prevents free circulation of the air into the muck below, and then drying and decay are much slower in their action. Eventually this layer attains such a thickness that further subsidence of the surface is scarcely noticeable.

Cultivation increases the subsidence directly by the mechanical effect of weight compacting the soil, and indirectly by accelerating the action of drying and decay. Muck soils that are so soft after drainage that they will not permit of the use of farm animals and machinery, are compacted from 4 to 6 inches by the first plowing. This first plowing is usually done with some form of tractor with broad wheels that cover practically all the surface plowed. Subsequently, when the muck is cultivated with farm animals and machinery, the surface receives unit pressures far greater than exerted by the broad-wheeled tractor, and a further compacting results. The underlying material turned to the surface by plowing is exposed to a greater drying action than otherwise would result. Decay, also, is hastened in the material thus brought to the surface. It is the experience in cultivating newly reclaimed muck soils that for a number of years after the first cultivation a uniform depth of plowing will bring to the surface each year a considerable layer of muck which was undisturbed by the previous year's plowing. This layer of new material decreases in thickness from year to year, until finally the cultivated layer attains such density that the combined forces of drying, decay, and compacting reduce its thickness very little. If the land is not plowed deeper than this layer the subsidence of the remaining muck is very slow; but if the land is plowed deep enough to reach undisturbed muck, further subsidence results.

LIABILITY OF BURNING.

In the reclamation of turf lands of this character there always is more or less danger that the muck will burn. On some of the newer plantations trouble has been experienced in burning off the growths of weeds and grass that covered the muck. This burning off can be done with safety only when the muck is wet from a recent rain. In the spring of 1910, which was the driest in southern

Louisiana since Government weather records have been kept in the State, the muck began to burn on subdistrict No. 3, near Raceland. This tract had been drained but about eight months. A rain of three-fourths of an inch failed to extinguish the fire. It became necessary to dig a ditch around the fire deep enough to reach to the silt below. This method of checking fire is practicable and efficient if it is adopted soon enough.

The danger that any considerable area of the reclaimed land will burn is very remote. The system adopted in reclaiming this land—that of dividing it up into comparatively small levee districts—would limit the extent of the fire, and the division of the districts themselves into small areas by the lateral ditches makes it impossible for the whole of any plantation to be in great danger from fire. The danger from extensive burning to the muck of unreclaimed swamp land is not great, even when the muck is very dry, for the ridges of river silt which occur at frequent intervals would serve as effectual checks to any great progress of the fire. Even if the muck be burned from a tract of land, the underlying silt makes a very excellent although a somewhat heavy and impervious soil.

The best preventative against the muck burning is cultivation. This prevents the growth of grass or weeds that might burn when dead or extremely dry. All such growth should be plowed under rather than burned, provided it is not so heavy as to make good plowing impossible. If it becomes necessary to burn the growth the burning should not be done when the muck is even partially dry. After several years of cultivation the muck will become much heavier and firmer and be much less likely to burn. However, in extremely dry times precaution should be taken to avoid burning any thing in the fields.

CROPS.

The staple crops grown in this section of the State are sugar cane, rice, corn, forage crops, and truck. In certain parts, especially along the lower portion of the Mississippi and in other districts near the Gulf, large areas are planted in oranges and other citrus fruits. In the eastern, or Delta, portion sugar cane is the most profitable general field crop, while in the western portion rice is grown almost as exclusively as is sugar cane in the eastern. Some corn is grown in both sections, but not enough to supply the local demand. Of the adaptability of the type of soil called the Sharkey clay, the Bureau of Soils says:[1]

The Sharkey clay was not especially adapted to cane and cotton and was no temptation to producers of these commodities, but the increased interest of late years in the production of rice has given a new value to this soil, and if the problem of drainage can be cheaply and successfully solved, the soil is admirably adapted to the production of this crop. Near New Orleans the reclaimed areas are devoted to the dairy business and to market gardening. The fertility of Sharkey clay is almost inexhaustible, and when well drained it is adapted to any crop which requires a fertile clay soil. The crops most profitably grown near New Orleans are onions, cabbage, eggplant, and tomatoes.

The soil is exceptionally easy to cultivate, due to the large percentage of vegetable matter present. In times of drought it retains moisture much better than the other soils in this section, and good crops have been produced on it when there were almost complete failures on adjacent sandy lands, owing to the lack of moisture.

While practically the entire list of staple and truck crops suitable to this climate have been grown profitably on the reclaimed areas, sugar cane, corn, and oats have been the principal crops. Yields of all crops have been good

[1] U. S. Dept. Agr., Field Operations of the Bureau of Soils, 1903, p. 452.

and compare favorably with the yields secured in the best sections of the Mississippi River Valley. The long growing season allows the planting of a winter crop of oats, which is harvested early in the spring so as to allow the planting of corn on the same lands so that it has ample time and favorable conditions for maturing in the autumn. The long and favorable growing season makes possible many combinations of crops. With some combinations the same area of land produces three crops in a year. The mild winters make stock raising profitable, as green feed can be grown during the entire year.

NATURAL DRAINAGE CONDITIONS.

The natural surface drainage of this section is away from the Mississippi River and larger bayous of sedimentation, directly into the Gulf by way of bayous of the tidal erosion type. However, numerous canals are being cut through the bayous of the first type from the low-lying swamp or prairie lands, thus aiding in the drainage. Water covers the surface of the undrained lands for the greater part of the year. This water comes from three different sources—direct precipitation, river overflow, and tidal overflow.

Overflow Due to Direct Precipitation.

The water to be removed from these lands comes mostly from direct precipitation, and it is with reference to the removal of this water that the nature and capacity of natural drainage channels will be discussed.

Owing to the slight elevation of the land above sea level, all of the streams are very sluggish in character. Their surface slopes always are very slight and are due entirely to the piling up of the water in the interior until sufficient head is created to force the water out to the Gulf. At times of high tide in the Gulf and small precipitation in the interior, the current often is reversed in many of the streams, and salt water then flows many miles inland. However, at such times the water in the channels is so low that the tide rarely causes a stage sufficient to flood any of the adjoining land. (This condition should not be confused with tidal overflow, which will be discussed later.) The fluctuation in water level, due to direct precipitation, in the various bayous and interior lakes is never very great and depends quite as much upon the direction of the prevailing winds as on the amount of precipitation.

Bayou Lafourche is one of the largest and longest natural drainage channels in this section, extending about 120 miles into the interior. A gauge has been maintained for more than seven years at a point about 70 miles inland from the Gulf, and back about 1 mile from the bayou on a canal which connects with the general water level in the swamps. The extreme variation of the water surface observed at this gauge was 4.5 feet. The lowest stage was caused by a prolonged and record-breaking drought in the spring of 1910, at which time salt water had reached the gauge. This reading, which is approximately sea level, was 1.3 feet below the average stage of water at this point. The highest stage was reached in October, 1916, after a rainfall of about 21 inches in 15 days, when the water stood 3.2 feet above average water level.

At points farther inland the fluctuation in water level is proportionately greater. The situation on Bayou Lafourche is mentioned because it is typical of all the long, sluggish bayous that carry away the drainage water. Most of the interior watercourses are connected with each other by cross bayous and canals, so that they are all somewhat similar in their action. The drainage areas are very poorly defined and no doubt lap somewhat, as some of the connecting canals and bayous often reverse direction of current according to the stages of water in the various parts of the system; for this reason it is prac-

tically impossible to measure the run-off from these drainage areas. It is probable that the natural run-off is very low, owing to small slopes and the rank vegetation on all the land, only about 10 per cent along the bayous being under cultivation. The bayous of sedimentation are quite free from growth of vegetation, many having a considerable boat traffic, which tends to keep them cleared out and in good condition as drainage channels. Those of tidal erosion are apt to be overgrown with water hyacinths, but owing to their greater depth these are also quite efficient channels.

As shown in figure 1, many parts of this section discharge their drainage water almost directly into the Gulf or into large interior lakes that undergo very little fluctuation in water surface. Thus these areas are relieved of all drainage water due to direct precipitation without great rise of water in the carrying channels. In the interior portions, such as that contiguous to the upper part of Bayou Lafourche, there often are rises of water level of several feet in the main drainage channels. In this flat country a rise or 3 to 4 feet in the main drainage outlet is a very serious matter and one that demands attention.

In reclaiming land in this section the usual practice is to inclose the district with levees to keep out the surrounding water; the drainage water of the land so inclosed is then pumped over the levee into some natural bayou that leads to the Gulf. If the fluctuation in water level in this outlet bayou is great, not only is a more expensive pumping plant equipment necessary, but the cost of the levees is very greatly increased. As the usual height of the levees is but from 3 to 5 feet above the ground level of the marsh, a rise of 3 to 4 feet in the outlet bayou will often endanger the levees, or at least cause a considerable seepage through them. The danger from seepage is especially great, because the fluctuation of the water level takes place very slowly. Several times in the past seven years the water has stood 1.5 feet above mean tide level for more than a month, and at one time it stood for more than a month 2 feet above mean tide. As a result, levees that were satisfactory in ordinary times allowed much seepage to enter the district they protected, and heavy and continued pumping was necessary.

Up to the present time little attention has been given to the problem of the disposal of the drainage water after it is pumped over the levees. Some sections never will be compelled to give this matter consideration, owing to their favorable locations on or near the Gulf or some other large body of water. On the other hand, there are sections of wet prairie that are isolated from any large bodies of water by distances of from 20 to 75 miles along the shortest natural outlet channel. In the first years of reclamation no difficulty was experienced in getting outlets, for the surrounding limitless prairie was so little above sea level that the drainage water spread out immediately, causing no trouble; but in some localities so much land now has been reclaimed that the effect on the carrying capacity of the natural watercourses is becoming noticeable. As the work of reclamation goes forward and district after district is reclaimed until a considerable portion of the whole area is appropriated, the drainage water, when pumped over the levees, can not spread over the surrounding prairie, for the latter will be inclosed by the levees of adjoining districts. The water then will be forced to flow through long winding channels to the Gulf, the distance often being as great as 75 miles. This will mean that the water level on the outside of these interior districts must rise until sufficient head is created to cause a movement of the water to the Gulf, thus greatly increasing the cost of reclamation and rendering unsatisfactory much of the work that is now apparently finished.

In the planning of gravity drainage districts the common interests of adjacent districts in securing good outlet facilities have long been recognized in all parts of the country. Experience has shown cooperation between such districts to be necessary. As yet most of the reclamation districts that secure drainage by pumping are independent of each other, and, as pointed out above, those which are fortunately situated will remain so. On the other hand, interior sections will eventually need better outlet facilities to the Gulf if the present policy of developing small independent districts is continued.

It is evident that the various districts should be so correlated that there will be no interference between the different interests. This makes necessary a general survey of this district, covering the topographic and hydrographic features. A survey of this scope would show the probable future necessity of increasing the present capacity of the natural drainage channels, or perhaps of providing additional outlet channels for some of the more isolated sections. It is quite likely that such additional channels could be used as commercial canals, thus making them doubly valuable. The section of the country lying between Bayous Lafourche and Terrebonne, in the parishes of the same names, is an excellent illustration of an area that eventually will need better outlet facilities, parts of this area now discharging drainage water through 80 miles of natural drainage channel to reach the Gulf. As shown by the gage at Lockport, the natural water surface in the swamps already has a large fluctuation, and any further extensive reclamation will considerably increase this fluctuation.

The drainage of nearly all the land in the above-mentioned section is now effected, and the owners of land now drained by gravity should cooperate with those owning pumping districts to improve the main drainage channels or construct new ones. The responsibility for improving and maintaining these main channels rests equally on all land in this area, although the assessments for the work would be made according to benefits. It would be far better to take proper action in time to prevent loss due to poor drainage, rather than to delay action until crop yields are decreased and land values depreciated.

River Overflow.

Like all delta regions, this one originally was subject to peroidic overflow. The smaller floods of the Mississippi River were confined within the natural levees that the stream itself has built up, but at irregular intervals of some years great floods would cover practically all of the delta for months. As soon as any serious attempt was made to bring this land under cultivation, levees were built along the Mississippi River banks to protect the lands from overflow. Finally districts were organized which included long stretches of river, and millions of dollars have been spent in levee improvements. This expenditure, with such Federal aid as has been available, has built a continuous levee system on both banks of the river throughout its length in the district under consideration. The levees have been increased in size as fast as the protected land could supply the money. In the earlier years, owing to insufficient cross section of levees and low grade line, crevasses were of frequent occurrence in times of high water. As more and more work was done on the levees a greater degree of protection was secured, and now crevasses are rare, although the levees are not yet up to the full height planned. However, the amount of cultivated land protected by these levees is increasing very rapidly, thus not only enhancing the security for bond issues necessary to finish the levees, but also increasing the revenue-producing power of the land to pay the annual tax to retire such bonds. The agricultural developments of southern Louisiana, which

are all dependent on this levee system, are among the oldest and most uniformly successful in the country. Engineers who have made a detailed study of the levee system are certain that with its completion this entire area will be protected from overflow of the Mississippi River.

The above remarks apply only to the alluvial section of the State, as very little land west of the Atchafalaya River is affected by Mississippi overflow. Some of the larger streams, such as the Calcasieu and the Sabine, flood the alluvial flats immediately along their banks to a depth of perhaps 4 or 5 feet, but as a whole the wet prairie lands of the western portion of the coast are free from river overflow.

Tidal Overflow.

The daily range of tide along this portion of the Gulf coast is small, the average being from 0.5 to 1.5 feet. However, as is true of all low, flat coasts bordering on wide areas of comparatively shallow water, heavy winds blowing for any considerable time directly on-shore may cause a rise of several feet in the water. Such rises commonly are called storm tides. Their effect is so great that often they reverse the ordinary tide, and the maximum height of water may be reached at the usual time of low tide. Storms of this character usually are confined to the months of August, September, and October, and are known as tropical hurricanes. Those severe enough to cause large rises in the tide occur at comparatively long and irregular intervals. Sometimes they will affect only a comparatively small portion of the coast line, while at other times a general rise of several feet will be recorded all along the coast line, with a limited region where the storm center strikes the coast experiencing a tide of perhaps twice the height of the general rise.

Within the period covered by the investigations three characteristic storms caused abnormal tides along the Louisiana coast. These occurred, respectively, on September 20, 1909; August 16–17, 1915; and September 29, 1915.[1] High-water records for these storms were collected and are shown on figure 1, the heights of water caused by the different storms being given in distinctive symbols. Where only one height is given, it is much greater than that for either of the other storms. While the centers of these storms did not follow the same path, the effects of all three were felt in varying degree on the entire coast. It is difficult to draw any general conclusions in regard to tides caused by tropical hurricanes. However, it is believed that it will be of value to summarize the facts that were observed in the very detailed examinations that were made.[2]

The highest tides and the greatest damage seem always to be east of the track of the storm center, and the effect of the disturbance usually extends farther to the east than to the west, although differences in character and shape of coast line sometimes will make the opposite true. Regions fairly close to the track, whether to the east or west, will suffer. The height of the tide depends on the intensity, duration, and direction of the wind and on the shape and exposure of the coast line. The offshore depth of water also will have some influence and the nature and amount of vegetation on the land will have a great effect on the heights at points not immediately on the shore line. Funnel-shaped bays facing directly toward the hardest wind are likely to have the highest tides, as shown by the records at the upper end

[1] For detailed descriptions of these storms see U. S. Dept. Agr., Monthly Weather Review for the months in which the storms occurred.

[2] For a full report of the investigations on storm tides along the central Gulf Coast, see special report of C. W. Okey, of September, 1916.

of Timballier and Terrebonne Bays and at the southwest end of Lake Pontchartrain. Low, barren strips of land like that near Port Eads, and islands like Timballier, which allow the water to pass on across without much obstruction, are not likely to experience as high tides as land which is higher or covered with trees, or as that portion of the mainland which is covered with a heavy coat of tall grass.

The rising water flows inland with considerable velocity and piles up on any obstruction, such as a railway embankment or a strip of heavy timber. Such an obstruction will delay the progress of the water until it rises sufficiently to pass over or around the obstacle. Usually sufficient time is not allowed for the water to assume anything near a level stage over any considerable area, and great differences of level are to be expected within a short distance, especially near the limit of overflow or where the water is obstructed. This is shown by the heights observed south of Houma, on Bayou Terrebonne, and between Michaud and Lee Station, on the Louisville & Nashville Railway. Quite often there occurs a shifting or even a reversal in direction of the wind as the water reaches its highest stage. This will cause great local differences in stage. Points a long distance from bodies of open water do not experience overflow from tides, as the water does not have sufficient time to travel inland before a change in the wind occurs, and heavy strips of timber retard the flow to a remarkable degree.

No method of forecasting the maximum height of water to be expected at a given point seems possible. However, as the highest stages recorded in the last three storms are the highest yet experienced in those comparatively limited areas, it is not likely that they will be exceeded soon. In the areas removed from the centers of these storms higher tides may be caused by storms striking the coast at other points, and future storms undoubtedly will cause tides which show a different variation, as between the various localities, from those already experienced. It is suggested that in estimating the height of tide to be expected at a given point an area in the region of maximum recorded tides which is similar in all features to the one in question be selected for comparison. As future storms may exceed those of the past in both intensity and duration, a margin should be allowed for safety.

From an examination of the heights reached by storm tides, as shown in figure 1, it would appear that reclamation districts on many portions of the coast will be compelled to build levees not only to keep out the waters of the surrounding swamps, but also to prevent tidal overflow in times of storm. The heights of tide indicated on this map are the highest experienced since the country has been settled, and they should govern the heights of levees in the various localities. Areas well inland from large bodies of water connecting directly with the Gulf need not expect to feel the effect of storm tides.

In connection with the general problem of protection from tidal overflow, the plan of providing a protection levee for the whole coast line, rather than that of constructing individual levees for each district, has been considered by local engineers. The feasibility and cost of such a plan could be determined only after a complete survey of the district had been made and a comprehensive plan had been carefully worked out. However, some general features can be stated to give an idea of the nature of the problem. The larger the levee district, other things being equal, the less the cost per acre for levee; for the length of the levee per unit of area, for districts which are roughly square, varies as one divided by the square root of the area. Moreover, doing work along broad lines and handling earthwork in large quantities will reduce the unit costs of construction. In fixing the outlines of such large areas advantage can be taken of many natural features of the land to be protected, which

will reduce further the cost of levee and drainage-channel construction. This will consist principally in utilizing the natural ridges as levees and the natural streams as drainage channels.

While it is not considered feasible to include the entire section under discussion in one or two levee districts, it would appear that the number of such districts could be made comparatively few; and if an attempt is to be made to reclaim any considerable areas near the coast line, or where the storm tides are likely to be above 6 feet, the question of a general protection levee for that section of the coast should receive careful consideration. Where the storm tides are likely to exceed 6 feet the cost of the levee will become such a heavy proportion of the cost of reclamation that often it will be proper to construct the general protection levees in advance of the construction of the other drainage improvements, that is, to give protection from tidal overflow to more land than is to be drained completely and utilized immediately.

DESCRIPTION OF RECLAMATION DISTRICTS.

Previous to about 1907 there had been no active movement in the drainage of the wet prairies lands of Louisiana. The older plantations along the Mississippi River and other large alluvial streams had extended their clearings back to the belt of cypress swamp that usually lies between the ridge along the streams and the grass-covered prairie; there, owing to the expense of clearing such land, further progress usually was checked. At some points, however, where this belt of timber was narrow, the plantations were extended to include relatively small areas of prairie land. Such areas were inclosed with levees, ditches were cut, and pumping plants installed. The land thus reclaimed on such a small scale has proved to be fertile and has been farmed with entire success.

About eleven years ago the present movement for reclaiming large areas of wet land began, and districts consisting entirely of wet prairie land were inclosed by levees, and drainage systems installed. The degree of success attending these early reclamations interested people from many points outside as well as within the State, and at present the amount of capital invested in drainage improvements is very great. From the drainage engineer's standpoint the work passed the experimental stage long ago, and by following the best methods used on existing districts the successful drainage of the average type of wet prairie land is assured. Many problems which in the earlier stages of the work confronted those in charge have been solved successfully by study and experiment. It is the primary purpose of this bulletin to set forth the results of investigations made so that one new to the work may readily become familiar with the best practice as carried on in the present state of development.

The degree of success attained in the various methods used in the reclamation of these lands has been investigated closely by this office. The investigation has included studies of the natural features of a number of drainage districts and of the levees, reservoir canals, field laterals, pumping plants, and methods of cultivation, as well as of the records of rainfall and run-off. A large number of districts have been examined closely, and practically every district within the State has been inspected.

To explain better the nature of the drainage problems encountered and the reclamation methods employed, a detailed discussion of some typical reclaimed areas will be given, and a summary of the results of all investigations presented. These examinations were made during the period from 1909 to the latter part of 1916, and descriptions refer to conditions obtaining during that time and at the end of the period.

EXPLANATION OF TERMS.

Before proceeding with the discussion of the reclamation districts a brief explanation of some of the technical terms hereinafter used will be given.

By run-off is meant the water that flows over or through the ground to drainage outlets. All run-off originates in precipitation; therefore the latter is the most important of all the factors that influence the rate of run-off, some other controlling features being size, shape, topography, and geological structure of the watershed, climatic conditions, and the character of the vegetation.

In so-called gravity drainage districts the run-off is removed by gravity through the main outlets. In pumping districts the run-off is collected at some point within the district and pumped over or through the levee. The rate of run-off is expressed as a quantity of water removed in a unit of time. This quantity of water can be conceived as a certain depth distributed uniformly over the entire drainage area. Similarly, the capacity of a pumping plant is the quantity of water, expressed in a depth distributed uniformly over the drainage area, that the pump can dispose of in a given time. As used in the following discussion, the rate of run-off is expressed by the depth of water, in inches, distributed uniformly over the drainage area, that passes from the area in a period of 24 hours. Likewise, pumping-plant capacity is expressed in terms of a depth of water, distributed uniformly over the drainage area, that can be removed by the plant in 24 hours of continuous operation. Reservoir capacity, also, is represented by a uniform depth distributed over the drainage area. The object of expressing the rate of run-off and the pump and reservoir capacities in depths rather than in volumes per unit of time is to arrive at a basis of comparison that is independent of the drainage areas. On any particular tract, the area being known, these rates can easily be reduced to cubic feet per second or to any other convenient unit.

In a long period the total amount pumped would equal approximately the run-off for that period; but for short intervals, as, say, 24 hours, the run-off from an area might be much greater than the quantity pumped, the excess being stored in the reservoir for subsequent pumping.

WILLSWOOD PLANTATION, WAGGAMAN, JEFFERSON PARISH, LA.

This plantation is selected for discussion because it is typical of the character of pumping district that was drained first in Louisiana. Conditions prevailing in this plantation are also typical of those on all river and bayou front lands, and as most of the land at present in cultivation in this section of the State is of this character, a rather detailed description of conditions will be given.

As shown in figure 3, this plantation, of 2,600 acres, fronts on the Mississippi River and extends back into the prairie swamp lands in the rear. About one-third of the area of the present plantation originally was prairie land and was included by an extension of the levees in 1896. A pumping plant was installed, and cultivation has been continuous since that date. The area of prairie land included was typical of such land in this part of the State and was covered with a scattering growth of willows and the usual rank growth of grass. Originally the muck was about 4 feet deep and was overlain by a layer of river silt about 4 to 6 inches thick, although at present, after 22 years of cultivation and decay, it is well compacted and has subsided or shrunk until it now averages from 2 to 3 feet lower than it was originally. The total fall in the surface of the ground from the front to the rear of the plantation is about 10 feet.

LEVEES.

As the front portion of this tract drains toward the land in the rear by gravity, it is inclosed only partially by levees. Starting where the ground is about 5 feet above mean Gulf level, levees were built around the lower portion to a height of nearly 7 feet above mean Gulf level. The levees were built by a dipper dredge with material taken from the inside of the district. The canal resulting from the levee building was used for a reservoir. The ground was quite soft, and the levees were built up in several layers, and owing to the

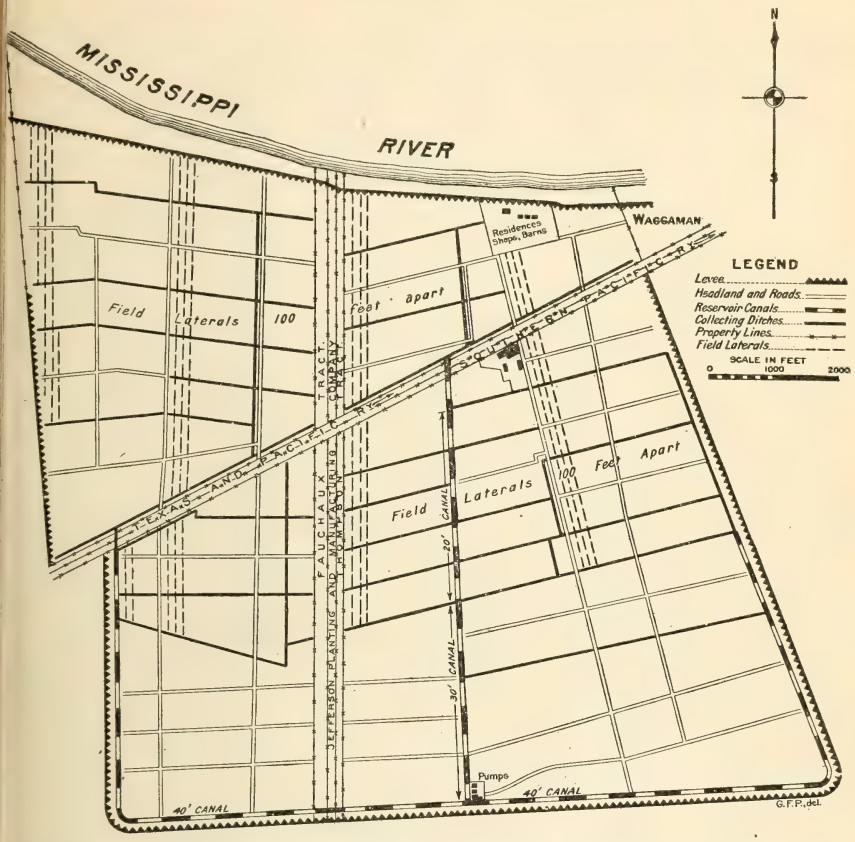


FIG. 3.—Sketch map of Willswood Plantation, Waggaman, Jefferson Paris, La., showing ditch and levee system.

soft nature of the ground the excavated material formed a good bond with the foundation. The berm left between the levees and canal was from 10 feet to 15 feet. In 1912 these levees were increased in height to about 9 feet above mean Gulf level by the use of a 1-yard orange-peel dredge mounted on a barge floating in the reservoir canal. The levees now have a top width of about 5 feet and side slopes of 2 to 1. As they stand to-day the levees seem to be almost impervious to seepage water. Nothing could be learned as to seepage water during the first year after construction, but the levees show no evidence of any sliding material due to seepage. The water usually is about a foot deep over the land on the outside of the district, though it sometimes

becomes somewhat deeper during heavy and continued rains. There often are periods of a month or two when the surface is dry.

Experience in other districts has been such that the locating of the reservoir canal immediately on the inside of the levee, using the material excavated from the canal in building the levee, might be expected to give trouble in causing a great deal of seepage through the levee into the canal. However, because of the great width and height of this levee the seepage is not noticeable. The subsoil under this levee is rather better than usual.

RESERVOIR CANALS.

By using these canals as a reservoir it was necessary to construct only a comparatively short canal into the interior of the district to give outlet to the collecting ditches. These are mostly about 5 feet deep, with 10-foot top widths and 3-foot bottoms, and serve as outlets for the small laeral ditches.

Until the levee was increased in height in 1912, the canals had not been cleared of silt since their construction, about 1896. They had needed clearing and deepening very badly for several years, as the water could not get to the pumping plant very rapidly after the level was reduced to about 2 feet below the land surface. Moreover, there was very little reservoir capacity available, and the canals had to be kept almost dry to afford a proper depth of drainage. After the material was taken out of the canals to increase the size of the levee they were of ample size. The pumping plant now can be operated at nearly full capacity until the water in the canal is reduced to a very low level, and the water comes from the farthest portion of the canal quite rapidly. Therefore it is not necessary to start the pumps so soon to take out the small amount of water that collects from ground-water drainage.

A considerable portion of the front of this plantation is high enough to drain by gravity. A diversion canal should be run across the front of the property so as to carry the water toward the eastern side of the plantation and thence into a canal which leads to land about 1 or 2 feet above Gulf level. This diversion canal or ditch should be connected with the outside of the district by means of a self-acting sluice gate which would insure against water coming in from the outside. The ditch would keep the water from the high land from pouring rapidly back toward the lower land near the pumping plant as it does at present. At times of very heavy rainfall a considerable area in the vicinity of the pumping plant is flooded for periods of from a few hours to more than a day. After most of the water from the higher land had been diverted outside, the district gates could be opened in the lower side of the diversion canal so that the low-water flow could go back toward the pumping plant and allow the canal to be drained completely. This improvement would save many floodings of the lowest portion of the plantation and also a considerable amount of fuel for pumping-plant operation. It is a feature which should be investigated very carefully when making a study of the best plan for draining lands of this character.

DITCHES.

The ditches on this plantation are of about the usual cross section on such lands, having depths of 3 feet, top widths of 3 feet, and bottom widths of 1½ feet. The spacing of the ditches varies with the character of the land. Thus, on the front lands, which are rather impervious, the spacing is about 100 feet, while on the newer lands taken in from the prairie the spacing is from 200 to 500 feet. On the front lands the laterals between collecting ditches are about 2,000 feet long; small, considering the large slope of the land. Conditions on similar plantations where the ditches are twice as long indicate that the laterals

on this district could be made of the same length. On the back lands, however, the ditches already are about as long as would be advisable, since the land is almost level. At present these ditches are too shallow to give adequate drainage. Some measurements of the depth of water table were made early in the summer of 1910. The results are shown graphically in figure 4. It is apparent that at that time this soil was not very impervious. Even after heavy rains the profile of the ground water was not steep. The ditches are too far apart for the best results, although if they were the full 3 feet deep they would drain the ground much better. Now that the reservoir canal is of a good depth these ditches could be cut as deep as 4 feet and still be pumped dry. If instead of cutting new ditches between the present ones lines of tile were placed midway, the purpose would be served even better and considerable land would be saved. The present ditches evidently are sufficient to take away the surface water, and, because of the open nature of the subsoil, the ground water would be taken away readily. The cost of maintenance alone on these extra ditches would nearly pay the interest on the cost of the tile work above that of the new ditches; in addition, there would be the saving in land. Furthermore, if tile were laid properly they would give the same amount of drainage all the time, whereas ditches give their best results only for the first few weeks after they are cleared of grass and weeds.

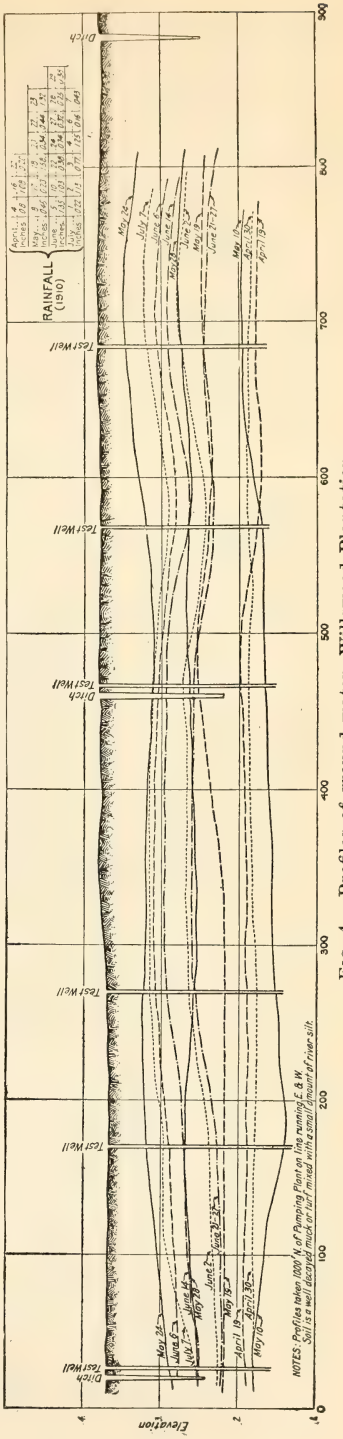

RAINFALL (1910)
Ditch
Test well
Elevation
NOTES: Profiles taken 1000 ft. N. of Pumping Plant on line running E. & W.
Soil is well decayed muck or turf mixed with a small amount of river silt.

FIG. 4.—Profiles of ground water, Willswood Plantation.

PUMPING PLANT.

The location of this plant is quite favorable, as it is on the lowest ground in the tract and at the junction of three large canals, making the distance the water must travel to reach the plant about as short as is practicable.

Steam for the three following pumping units is furnished by two water-tube boilers and one return tubular boiler, crude oil for fuel and a feed-water heater being used.

First, a rotary chamber-wheel pump, having a capacity of 40,000 gallons per minute, rope driven from a 16 by 24 inch automatic, noncondensing engine; second, one 42 by 16 inch Menge pump, connected by a rope drive and a bevel gear to a 16 by 24 inch automatic noncondensing engine; third, one

centrifugal pump with 36-inch diameter discharge pipe, direct-connected to a double, vertical engine. Pumps 1 and 2 discharge into open flumes at an average head on pump of about 10 feet, which is about 5 feet greater than necessary. Pump 3 has a siphon on the discharge pipe, but the end is not always submerged.[1]

The capacity of this plant usually has been large enough to remove the water before any damage has resulted from flooding. Due to the use of rope drives, the plant has been stopped several times for repairs when the loss of a pump was a serious matter.

As a whole the plant is very inefficient, but is quite typical of the pumping plant usually found on the old river-front plantation. Owing to the excessive lift, the cost of pumping is considerably higher than it should be. In another portion of the bulletin will be seen figures covering the detailed cost of operation for this and other plants. The main defects of this plant are a long and poorly designed set of piping on the 36-inch centrifugal pump, open sluice discharges on the other two pumps, causing an unnecessary lift of about 5 feet, and rope drives on two of the pumps.

Condition of Land for Cultivation.

For two years after the tract of prairie land in the rear of this plantation was reclaimed it was cultivated with only such drainage as was afforded by the reservoir canals. Then the present lateral ditches were cut, and good drainage was secured for a number of years. Not much detailed information was available concerning conditions in this early period. It is known, however, that during this time excellent crops were grown on the prairie land and that these crops were uniformly better than those grown on the older front lands. Until the last seven or eight years the prairie lands were so much better drained than the front lands that plowing could be done on the former when the water stood on the surface of the front lands. As is shown by figure 4, the depth of drainage was not much over a foot in 1910. This condition has been bettered somewhat by the deeper canal. However, crops were reported as being good, even with such shallow drainage. The fact that the crops did not seem to stand drought well undoubtedly was due to the very shallow depth of root growth that such a small depth of drainage would permit. As this tract is a part of the typical wet prairie land found in this section, the results obtained show that the successful reclamation of these lands is a certainty.

NEW ORLEANS LAKESHORE LAND CO. TRACT, NEW ORLEANS.

This tract lies along the southern shore of Lake Pontchartrain, about 4 miles east of the northern limits of New Orleans. As shown in figure 5, the frontage on the lake is about 7 miles. The width at the eastern end is about 2 miles and at the western 1½ miles. Most of the surface originally was covered with a heavy growth of grass, with only a small percentage of the area timbered. The elevation of the surface was a few inches above mean lake level, and except for a few small ridges and shell mounds the tract at one time was subject to overflow whenever the lake was at high tide. A considerable depth of turfy humus or muck covered the entire area; the range in depth was from 1 foot along the lake shore to as much as 10 feet in the portion 1 mile back from the lake. The average depth of muck was perhaps 5 feet.

[1] U. S. Dept. Agr., An. Rpt. Office Expt. Stas., 1909, p. 420.

Reclamation work was first started in 1908, and a small pumping plant was erected at the eastern end of the tract. Construction of the interior canals and the building of the levee followed. While the levee was carried entirely around the district to a moderate height, the canals were not all cut for several years. After the early part of 1913 construction work was carried on more rapidly and was practically completed in the latter part of 1914, except for the small field ditches. A second pumping plant was erected during 1913. The details of the improvements will be given with reference to their condition in the latter part of 1916.

LEVEES.

On the west end and the north side of this district the embankment of the New Orleans & Northeastern Railroad forms a levee with a height of about 10 feet above mean Gulf level. On the other two sides a levee was built with material taken from the outside of the district by a long-boom, orange-peel floating dredge. No muck ditch was cut under the levee, as the material was very soft, so that the top sod was well broken by the falling earth. The berm allowed was about 15 feet. This levee was raised and smoothed by handwork so that the

FIG. 5.—Sketch map of New Orleans Lake Shore Land Company tract.

top width was about 6 feet, the side slopes 2 to 1, and the elevation about 5 feet above mean Gulf level. After this treatment by hand the levee seemed to be free from seepage. The portion of the levee toward the east end of the district was raised in 1916 to about 10 feet above mean Gulf level, and the new levee then was carried directly south to connect with and become part of the lower protection levee of the city of New Orleans. This extension is not shown in figure 5. The material in these levees was placed in several layers and time allowed for each layer to dry and harden before the next layer was placed. In this way a sliding of the base of the levee into the canal was avoided, although the base will subside considerably and the material shrink a great deal in drying. On similar work elsewhere the amount of material measured in excavation is often two or even three times as much as the net section in embankment.

RESERVOIR CANALS.

A considerable portion of the reservoir canals of this district were first cut with a short-boom, bank-spud dipper dredge. As a result the canals were left in very poor condition. The banks were too soft to hold the spuds, and the

boom was too short to allow the material to be placed far enough back to be stable. Later the canals were all reexcavated with an orange-peel bucket dredge with vertical spuds, a 73-foot boom, and a hull only 24 feet wide. This allowed the maximum width of berm along the sides of the canal. This dredge went over portions of these canals as many as four times, for in spite of the long boom and wide berm the sides of the canals caved. The final cleaning out was done by a skid excavator mounted on the spoil bank of the canal. This excavator swung a one-third yard orange-peel bucket on a boom 40 feet long and was driven by a 15-horsepower internal-combustion engine. While this machine was working the water could be held at the bottom of the canal, and the soft mud which could not be picked up by the floating dredge was then solid enough to be taken out. The banks were sloped off by hand where they were not secure and the material allowed to fall into the canal to be picked up by the excavator. The first cost of this excavator was not nearly so much as that of a floating dredge suitable for doing the same work, and the excavator could do the clean-out work much more effectively. The unit price for this work was not greatly in excess of the cost of work done by the floating dredge, considering that it was of much smaller capacity. With the exception of the hydraulic dredge, the dry-land excavator is about the only practicable machine for such work.

The numerous reservoir canals on this tract give all parts of the land complete drainage. Their unusual depth, coupled with the fact that the water is held about 6 to 7 feet below the surface, gives the land a greater depth of drainage than on any other project examined. Although much care was used in lowering the water in these canals, slides and caving of the canal banks were not avoided entirely.

Ditches.

The spacing of ditches, averaging about 1,320 feet, was made to fit the subdivision of the land into 5-acre lots. The average depth of the ditches is nearly 5 feet, the top width about 4 feet, and the bottom 1 foot. The ditches are kept in very good condition, and it has been found that vegetation does not grow so readily in the bottom of a deep, narrow ditch as in a broader one not so deep. The water level is nearly always low enough in the large canals to keep the bottoms of the ditches free from water. The average length of the ditches is ¼ mile, which is about the proper length.

Prior to 1913 only a small portion of the district had been ditched. By the end of 1913 about 2,000 acres toward the eastern end had been ditched, and by the end of 1914 the ditched area had been increased to 5,400 acres. Ditching operations were continued during 1915, and by the latter part of 1916 the area was completely ditched. A large share of these ditches were cut by a wheel excavator supported on apron tractors, which cut a ditch about 4 feet wide at the top, 4 feet deep, and 18 inches wide at the bottom. The remaining ditches were cut by hand, and all were deepened by hand. The soft material which collected in the bottoms of the ditches soon after they were cut was taken out by hand also. After the soil became well-drained it solidified considerably, so that at present the ditches appear to have firm sides. However, they require cleaning at least once a year.

Pumping Plants.

There are two pumping plants on this district. The first was installed at the eastern end in the latter part of 1908. It consists of a 48-inch, cast-iron, double-suction, horizontal, centrifugal pump direct connected to a 16 by 36 inch Corliss engine, to which steam is furnished by a water-tube boiler. Coal is

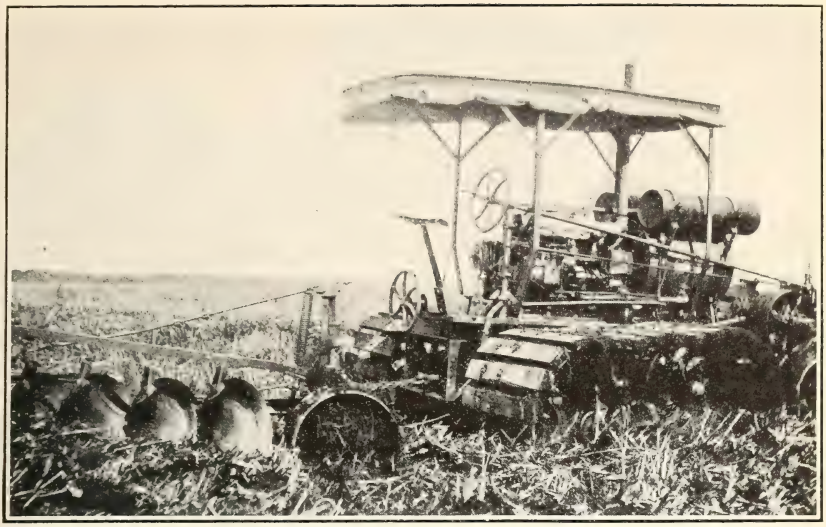


FIG. 1.—TYPE OF DISC PLOW AND TRACTOR USED IN FIRST PLOWING OF NEW ORLEANS LAKESHORE LAND CO. TRACT.

FIG. 2.—VIEW OF WET PRAIRIE BEFORE RECLAMATION.

used as fuel and is delivered by rail to a point about 300 feet from the plant. The suction pipes are rather longer than is usual in such plants; they were made so to reduce the amount of seepage from the discharge basin across to the suction basin. The ends of the suction pipes are expanded moderately, so that the entrance losses are not great. The discharge pipe discharges below low water and gives a full syphon effect, but as it is not expanded, the losses

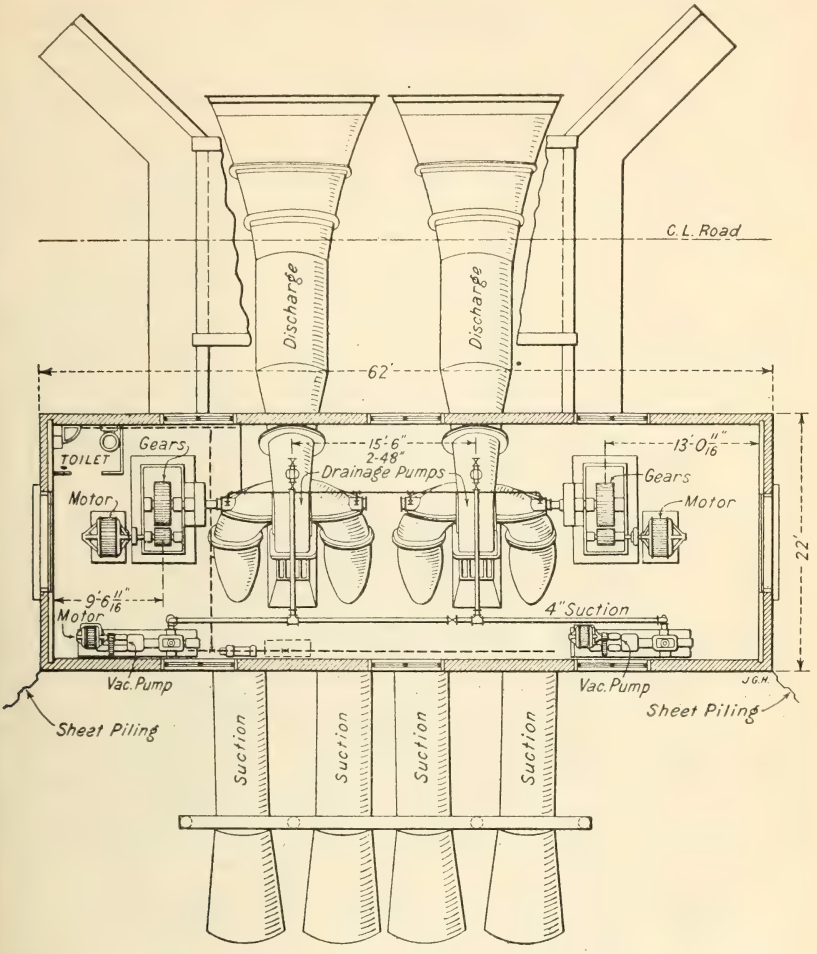


FIG. 6.—New pumping plant on the New Orleans Lake Shore Land Company tract.

of velocity head in this pipe probably are often equivalent to 2 feet of vertical lift. The direction of the water as it leaves the pipe is such that it is directed against the bottom of the discharge basin; this results in a deep hole being washed out, making it necessary that the sides of the basin be protected with a row of round piling.

As this plant was not of sufficient capacity to drain the entire area, a second pumping plant was erected in 1913 in a more central location on the north side of the district. The new plant has two duplicate units, each consisting of a 48-inch cast-iron, double-suction, horizontal, centrifugal pump, connected by

means of a herringbone gear to a 215-horsepower motor. Current is supplied by a power line from an electric company in New Orleans. The pumps are primed by means of a chamber-wheel vacuum pump driven by an auxiliary motor. The machinery is housed in a stucco-covered concrete building with structural-steel framework. The suction pipes are expanded at their ends with a long taper, so that the entrance and friction losses probably are less than 0.3 foot. The pipes are cut vertically at the end, and a row of sheet piling has been driven in the suction basin to form a funnel to direct the water into the ends of the pipes. As shown in figure 6, the pumps have an overshot discharge and are set so that the discharge openings are above high water in Lake Pontchartrain. The pipes are enlarged with a long taper so that the loss of velocity head is probably less than 0.3 foot.

The foundation of the building and machinery is supported by round piling, and the whole is inclosed by a wall of steel sheet piling driven deep into the sand. This sheet piling forms a bond with the concrete foundation.

Condition of Land for Cultivation.

From 1908 to 1913 only about 600 acres were drained. During this time only a very small amount of land was cultivated, and this was almost entirely the firmer soil along the lake. By the end of 1913, 300 acres were cultivated; during 1914, 1,700 acres; during 1915, 4,500 acres; and by the end of 1916, 6,000 acres. This land was brought in as fast as it was well drained. Usually the land ditched one year was cultivated the next. In bringing the land under cultivation the heavy growth of grass and considerable scattering brush were removed by burning, or by cutting and burning. Most of the cutting of the grass was done with power machinery. Light automobiles were rebuilt so as to have sheet-iron rimmed wheels with a width of 15 inches. These were used in drawing mowing machines mounted on wheels with wide treads. Each mowing machine was driven by a small independent gasoline engine mounted on the mowing machine itself. The land then was plowed with large disk plows drawn by tractors (Pl. I, fig. 1). After the land had been harrowed and allowed to settle for a short period it was usually possible to work farm animals on the land, provided the weather was reasonably dry and the feet of the animals were equipped with broad shoes locally known as "bog shoes." The first crop planted usually was corn. This was followed by various truck crops or corn the next year. The surface of the land rapidly became firmer, and during the second year of cultivation, except in wet weather, ordinary farm animals could work without difficulty. As rapidly as the land came into good condition it was planted in citrus trees and the cultivation of field crops continued between the rows.

DES ALLEMANDS DRAINAGE DISTRICT, DES ALLEMANDS, LA.

This tract (fig. 7) has been drained since the latter part of 1911. It lies on the western side of Bayou Des Allemands and south of the Southern Pacific Railroad. A portion of the town of Des Allemands is located in the northeast corner of the district. The land is from 1 to 2 feet above the ordinary stage of water in the bayou, and a large percentage is made up of firm silt ridges with a very thin layer of muck on the surface. Old muck-filled bayous, having widths of from 100 to 200 feet, occur at intervals. The muck in these is from 4 to 8 feet in depth. However, the land mostly is quite firm, the proportion of soft ground being about 10 per cent. The average depth of muck was from 8 to 18 inches. Except for a few scattering trees on the ridges the land originally was covered with the usual heavy growth of natural prairie grass.

LEVEES.

On one side the embankment of the Southern Pacific Railroad serves as a levee, and on the side bordering the bayou an almost continuous ridge of silt, averaging about 2 feet above ordinary water level, makes an excellent foundation for the levee. This levee was built in two layers by a floating dredge with material taken out of the bed of the bayou. The height is about 5 feet, the top width from 6 to 12 feet, and the side slopes 1½ to 1. After the first layer of material was placed in the levee a muck ditch about 3 feet deep was dug along the inside toe of the slope, and when the second layer of material was placed this ditch was filled with pure silt taken from the bottom of the bayou. This made the levee free from seepage through the base. On the other two sides the levee was located through softer land. Some years before the building of the present levee a canal had been cut along these two sides of the district. The spoil bank of this canal formed the base of the levee, although it was necessary to cut a muck ditch along the inside slope to cut off

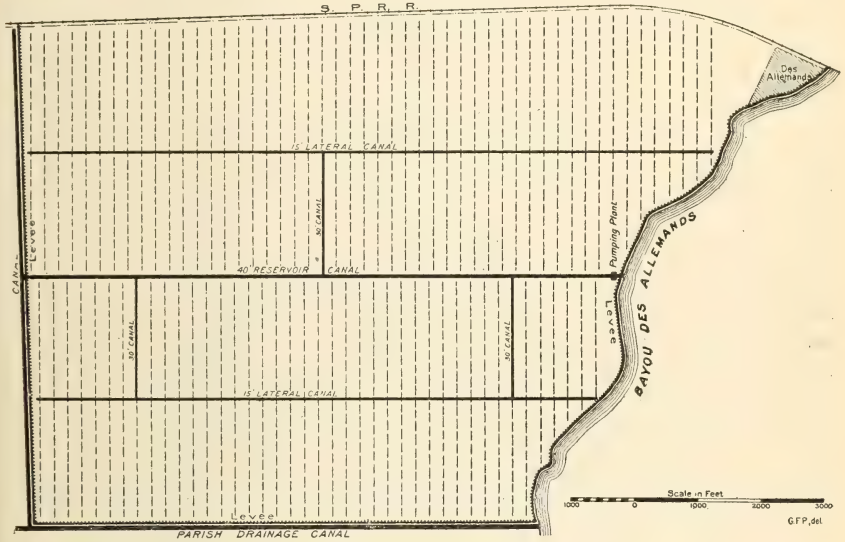


FIG. 7.—Sketch map of Des Allemands Drainage District, La Fourche Parish, La., showing arrangement of levee and ditches.

possible seepage. This portion of the levee was built up in two layers to a height of 4 feet, with a top width of from 4 to 6 feet and side slopes about 2½ to 1. The berm varies from 5 to 10 feet. Except where some old muck-filled bayous were crossed, the levee is up to the above grade. Many layers of material have been placed in these soft spots. The only method that seemed to be effective in raising this levee was to bring material in wheelbarrows from the solid banks of the bayou. After each layer was placed there was some subsidence, but gradually the top of the levee was raised. After the solid material placed in the levee reaches the solid bottom of the old bayou the levee should be free from further subsiding, except for the decay of the vegetable material in the soil, which will cause a gradual subsiding in all levees in this section.

On a portion of the levee in the northwest corner of the district very severe seepage conditions existed in 1912. Water appeared in springs as far as 100

feet from the levee. The foundation at this point was of solid silty clay, but examination showed that the ground had been honeycombed to a depth of several feet by muskrats or alligators. A trench about 14 feet deep was dug immediately along the inside of the levee by means of an orange-peel bucket dredge which floated in the outside canal. The material excavated from the trench was then dropped back into it from a height of about 25 feet by the same dredge, and the seepage was stopped entirely. No further seepage has been noticed.

Reservoir Canals.

As shown in figure 7, the reservoir canals were all cut in the interior of the district rather than along the levee. By extending the canals to all parts of the tract the necessity of small collecting ditches was eliminated. A small canal gives a much better outlet to the ditches than does the collecting ditch and is easier to maintain in good condition. Such canals can be of sufficient depth to have from 1 to 2 feet of water in them to discourage the growth of grass. These canals were cut with a small dipper dredge, and the material was deposited rather too close to the sides of the canal. This resulted in a certain amount of shrinkage in the size of the canals, and by February, 1912, there was from 2 to 4 feet of soft mud in them. A small hydraulic dredge was tried at cleaning out this mud, but was not successful owing to faults of construction in the dredge. A large orange-peel dredge was used to clear the main canal of silt in the latter part of 1913, but the lateral canals were still in poor condition. From that time until the summer of 1916 the capacity of the canals was not sufficient to bring the water to the pump rapidly enough to secure operation at full capacity, except when the stage of the water was very high. When the canal was empty at the pumping plant the water was still relatively high in the farthest corner of the district. In 1916 these canals were cleared of soft mud and enlarged somewhat by the use of a 1-yard dipper dredge mounted on an 18-foot hull and swinging a 35-foot boom. The width of the main canal now is about 42 feet and that of the small canals about 20 feet. The average depth was increased from about 5 to 9 feet. With this increased depth and width good drainage is insured for the entire district, and the pumping plant can be operated continuously until the water at the far end of the district is lowered enough to give good drainage. Prior to this clean-out work it was necessary to run the pump a few hours and then wait for the water to come in slowly to the plant.

The canals originally were smaller on this district than has become good practice, but if they had been cleared of silt early in 1913 there would have been little interference with drainage. Such clearing out of the canals should be done after they have been cut two or three years and the district drained for a year or two. The material along these canals is now quite solid, and a second clearing of the canals should not be necessary for a long term of years.

Ditches.

The spacing of the ditches on this tract is 210 feet. They are of about the usual size, 3 to 4 feet deep with a 4-foot top and a 1-foot bottom width. All discharge into the smaller lateral canals. Thus any silt which is carried along in the ditches is deposited in the small canals and does not choke up the large canals. Due to the regular shape of the district and to the good layout of canals, the ditches are all of about the same length, 2,000 feet, which has proved to be satisfactory where ditches are kept in good condition. However, in the portion of the district between the railroad and the nearest lateral canal the problem of getting the water from the far end of the small ditch into the canal

has been made harder because the land near the railroad is from 1 to 2 feet lower than that near the lateral canal. As a result the ditches have had to be 5 feet deep near the lateral canal in order to give a scant 2 feet of drainage near the railroad. While the surface of most all the prairie lands is nearly flat, it is best to take advantage of the natural slopes in laying out the field ditches.

Ditching operations were started in 1911 and continued through the following years as the land was desired for cultivation. All of the land between the main reservoir canal and the railroad had been drained in 1915 with ditches spaced 210 feet apart, and the land on the other side of the main canal had been partially drained with ditches spaced about 840 feet apart. As soon as this land is needed for cultivation it will be ditched completely.

Pumping Plant.

The pumping plant is located about 300 feet back from the bayou front, on a leveed outfall canal. This location was selected that advantage might be taken

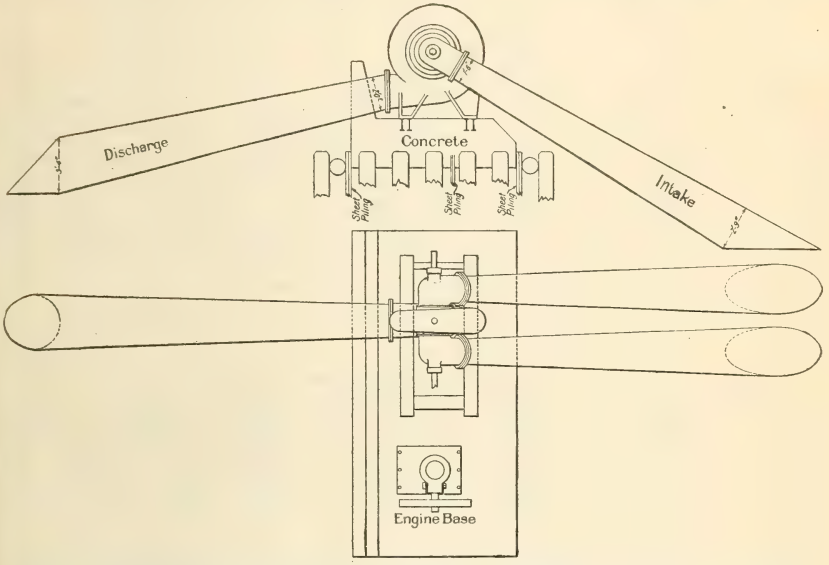


Fig. 8.—Sketch plan and elevation of one unit in pumping plant on Des Allemands Drainage District.

of a firm ridge of silt as a foundation for the machinery. The arrangement and character of the foundation are shown in figure 8. There are two duplicate units, each consisting of a 24-inch, cast-iron, double-suction, horizontal, centrifugal pump, direct connected by means of a flexible coupling to a 12 by 12 inch, vertical, slide-valve steam engine. The suction and discharge pipes are tapered their entire length so that the area of the end of the intake is four and one-half times and the area of the discharge pipe three times that of the discharge opening on the pump. This enlargement of the pipes probably reduces the friction and velocity head losses to less than 0.5 foot, while if they were not enlarged the losses would amount to nearly 4 feet. These pumps operate efficiently, as everything within reason has been done to cut out unnecessary losses. Steam is furnished by two Scotch marine boilers, burning fuel oil. This type of plant is reliable and easily operated, but uses considerably more fuel oil than does the best type of steam engine or an internal-combustion engine. Both units have been run for periods of four or five days without stopping.

Condition of Land for Cultivation.

A considerable area on this tract was firm enough to plow with ordinary farm animals. The muck was only about 8 inches deep, and the material underneath was solid and sandy. The grass was burned off and the land then plowed with large disk plows. In addition, both round-wheel and apron-wheel tractors were used to pull gangs of disk plows which broke up the ground in an excellent manner. The ground then was pulverized with a disk harrow and planted in corn. Even on the softest of the land, after one good plowing and subsequent smoothing by tools drawn with the tractors, ordinary farm animals were used to cultivate the crop. After the second year of cultivation the shallow muck had become so mixed with the underlying soil as practically to disappear. Even the deeper muck is becoming compacted rapidly into a firm soil. By the end of 1913, 250 acres were cultivated; in 1914, 600 acres; in 1915, 800 acres; and in 1916, about 1,000 acres. The land, which was drained by ditches 840 feet apart, was partially utilized for pasturing cattle.

GUEYDAN DRAINAGE DISTRICT, SUBDISTRICT NO. 1, GUEYDAN, LA.

This district, containing 5,600 acres, is the first one developed in the southwestern part of the State. The general nature of the soil and other natural conditions already have been described. The elevation of the surface is between 1 and 3 feet above mean tide level, and the slope of the surface is from north to south. This tract is typical of the harder prairies of this section as compared with those of the softer type immediately along the rivers of this part of the State (Pl. 1, fig. 2). Work was begun on this district in June, 1911, and the pumping plant was started in March, 1912. Figure 9 shows the general arrangement of canals, levees, and ditches.

Levees.

Along the north side a drainage canal had been cut some years prior to the beginning of the present work. A spoil bank of a cross-sectional area nearly sufficient to serve as a levee remained on this canal and was utilized in making the levee for this area. Along the other three sides the canal cut to get material for the levee is on the inside of the district. In cutting a canal 5 feet deep and 25 feet wide sufficient material was secured to build a levee with a height of 5 or 6 feet and a top width of 5 feet. Owing to the solid nature of the subsoil the levee subsided very little, except where some old muck-filled bayous were crossed. The berm left on most of the levee work was less than 8 feet, and no muck ditch was used under the levee. Taking into consideration the facts that the base of this levee was from 2 to 3 feet above mean tide, that the water never becomes more than 3 feet deep on the original general land surface, that the subsoil is very solid, and that the average depth of the muck is about a foot, it would seem to have been good practice in this case to place the three new levee canals on the inside of the district and thus have use of them for drainage canals, except where the old muck-filled bayous were crossed. While in general the levee has given satisfaction, even when for nearly a month the water was 3 feet deep on the surrounding prairie, yet where the levee crossed the muck-filled bayous a considerable expense was necessary to make it safe, and at these crossings the canal should have been on the outside of the district. A dipper dredge was used to place several layers of material at these weak points, until it became apparent that the levee could not be built up to the required size by such means. The depth of the bayou varied from 1 to 15 feet, with an average of about 10 feet. The water pressure from the outside forced the levee into the interior canal. A railway trestle was built along the

center line of the levee, and heavy clay was hauled in and dumped into the bayou until the levee was built up sufficiently high. While the weight of the clay was sufficient to force it down through the muck to the bottom of the bayou, the presence of the muck caused the clay to slide laterally and made it necessary to reconstruct the trestle before the levee was finished. If the muck had been removed from the site of the levee before the clay was dumped it would have made construction easier.

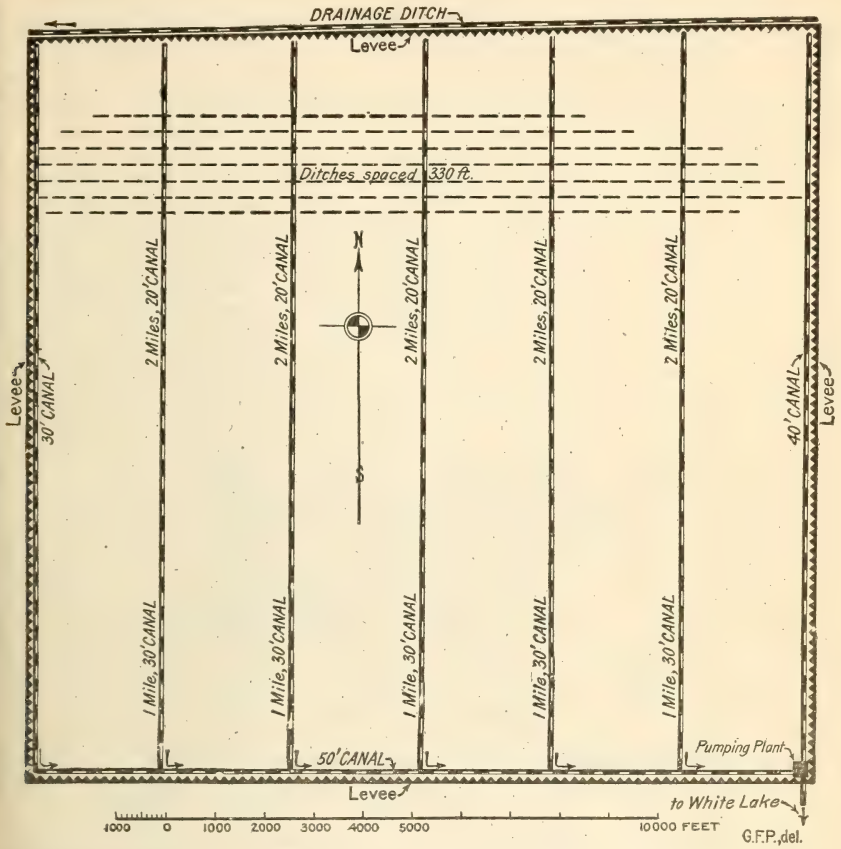


FIG. 9.—Sketch map of Gueydan Drainage District, Subdistrict No. 1, showing ditches and levees.

RESERVOIR CANALS.

In addition to the canals that border the district, collecting canals were cut every half mile. (See fig. 9.) These were from 8 to 9 feet deep and the main reservoir canal from 10 to 12 feet deep. The canals have maintained their original widths and have very little soft mud deposited in the bottom. Their banks have stood perfectly, although a considerable amount of boat traffic has been going on. They are deep enough for navigation, even after the water is lowered sufficiently to drain the land. This interior navigation has been of considerable advantage in the farming operations. In addition, the unusually large storage capacity has furnished a water supply with which to irrigate the rice crops.

Ditches.

Lateral ditches were cut with an apron-traction ditcher at a uniform spacing of 330 feet and 1,320 feet long. These machines worked in from 1 to 3 feet of water. Owing to the solid nature of the subsoil the apron wheels did not sink into the ground to any great extent. Because no openings were left by the dredges in the spoil bank along both sides of the canals, cutting by hand was necessary to connect each ditch, and as the spoil banks frequently were 10 feet high, the expense was considerable. However, the frequent and regular lateral canals made it an easy matter to install an efficient system. The ditches were cut a little more than 4 feet deep, with a top width of 4 feet and a bottom width of 1½ feet. The ditches have maintained their size and shape very well in the firm subsoil of this district and have filled badly only in the deep, soft muck in the old bayous.

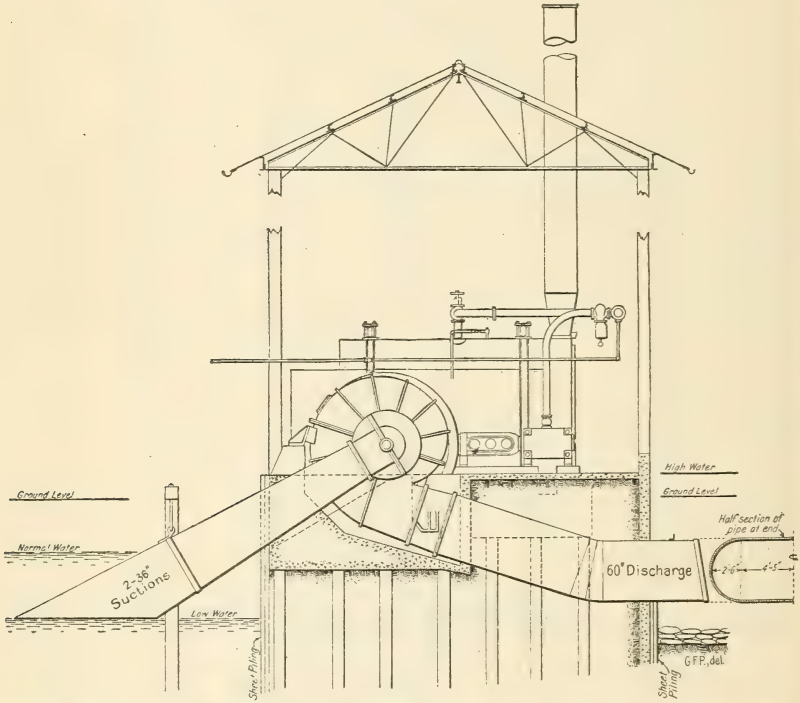


Fig. 10.—Elevation of pumping plant on Gueydon Draining District, Subdistrict No. 1.

Pumping Plant.

This fireproof plant was located in the corner of the district, so that it would be near an outlet canal to be dug to White Lake, about 6 miles to the south. By placing the plant in the middle of the south side of the district the length of canal to the farthest portion of the district could have been reduced from 6 to 4½ miles.

There are two duplicate units, each consisting of a 54-inch, cast-iron, double-suction, horizontal, centrifugal pump, direct connected by a solid shaft to a 16 by 36 inch Corliss engine. As shown in figure 10, the suction and discharge pipes are so designed that the friction and velocity-head losses are small, less than 0.5 foot on test. Steam is furnished by two return tubular boilers burning fuel oil. The feed water is heated before entering the boiler. The machinery is

mounted on a concrete foundation supported on piling driven in unusually hard subsoil. This plant was found of ample capacity to drain this area of 5,600 acres, and an additional area of 2,000 acres was placed tributary to the plant. The building inclosing this machinery is a frame of structural steel, covered with heavy corrugated iron.

Condition of Land for Cultivation.

Owing to the solid nature of the subsoil, cultivation was started on this area a few weeks after the pumping plant had removed the water. By April, 1913, a year after the pumps were started, about 500 acres were plowed. A gang of moldboard plows, drawn by a heavy apron-wheel tractor, was used. After the tough sod had been pulverized with a tractor-drawn disk harrow the land was cultivated successfully with ordinary farm animals and machinery. On the deeper muck near the south end of the area, plowing was done with a large disk plow drawn by tractor. In 1914 a little more than 600 acres were cultivated, in 1915 about 1,000 acres, and in 1916 about 1,500 acres. Most of this cultivated land was planted in rice, and the water for irrigating it taken from the interior reservoir canals. During the months when water was used for rice irrigation (June to August, inclusive) the amount of water that the large drainage pumping plant took out of the interior canals was very small. When the water was drained off the rice field, preparatory to cutting, a considerable volume of water had to be pumped.

RESULTS OF INVESTIGATIONS OF RECLAIMED TRACTS.

Table I gives a summary of all the details of reclamation and the prominent natural features on the areas already described, with corresponding data on a number of other districts. No detailed descriptions of these latter districts will be given, as conditions on them are in general similar to those on the districts already described. In explanation of this table the following notes are given:

In calculating the percentage of land that is in lateral ditches it was considered that for each ditch a strip of land 6 feet wide is lost to cultivation.

The reservoir capacity, in inches of depth over the whole area, includes the capacity of all canals between the general surface of land and the water level 5 feet below the surface.

The pumping plant capacity was based on a velocity of 12 feet per second through the discharge openings of the pumps.

FACTORS AFFECTING DRAINAGE BY PUMPING IN SOUTHERN LOUISIANA.

While the detailed descriptions of the four typical districts and the data in Table I give a general idea of the drainage problems and the methods used in solving them, it is believed that it will be of service to point out some of the usual faults of plan and construction and to describe the best methods being used in the design and construction of the drainage works.

INVESTIGATIONS TO BE MADE BEFORE RECLAMATION.

Before attempting to reclaim any body of wet prairie land, the following points should be investigated thoroughly:

(1) The depth and character of the muck;

(2) The character of the underlying silt;

(3) The elevation of the land above ordinary stages of the water in the surrounding lake and bayous;

(4) The ordinary and extreme variation of the water level in these lakes and bayous;

(5) The elevation of the ordinary and maximum storm tides and the rate of rise and fall;

(6) The amount and character of sunken timber and stumps;

(7) The character of the timber or grass on the surface; and

(8) Transportation facilities.

In addition, the topographic features of each district should be investigated in detail by a careful field survey, and a complete and definite plan and estimate of cost worked out by a competent engineer. The work should be constructed under competent engineering supervision and should be of a permanent nature, since the need for the improvements is permanent.

AREA OF THE DISTRICT.

Although topography has a large influence in many localities in fixing the area of a reclamation district, there are many large bodies of land of such a character that the size of the unit would be determined almost entirely independently of topographic conditions. In order to make clear the conditions governing the determination of the most desirable size of unit, the respective advantages of the small and large districts will be enumerated. The principal advantages of the small unit are:

(1) Short internal drainage canals with small losses of head, and the consequent low lift;

(2) Short haul to outside water transportation;

(3) Small area affected in case of failure of protection levee;

(4) Small capital involved; and

(5) Short time required to place land under cultivation and early realization on investment.

Districts in so

Reservoir capacity.	Pumping capacity in 24 hours.
Inches.	*Inches.*
0.88	1.23
2.20	.93
.70	1.06
.81	1.69
.50	1.25
.40	2.15
.67	1.91
.50	1.50
.....	1.40
.66	1.60
.50	1.42
.34	.95
.66	1.58
.35	1.33
.66	.....
.66	1.58
.42	1.01
.....	1.28
1.17	1.35
.42	1.60
.63	1.75
.60	1.44
.97	1.81
.....	1.04
.90	1.17
.....	1.03
.90	2.55
1.00	1.38
.28	1.56
.66	1.62

TABLE I.—*Summary of natural conditions and drainage features on thirty reclamation districts in southern Louisiana.*

Area No.[1]	District.	Parish.	Town.	Area.	Original depth of muck.	Elevation above mean Gulf.	Height of storm tide.	Height of levees.	Spacing of laterals.	Size of laterals. Top.	Size of laterals. Bottom.	Size of laterals. Depth	Length of laterals.	Depth of water table.	Land in ditches.	Land in canals	Reservoir capacity.	Pumping capacity in 24 hours.	Pumps.	Engines.	Boilers.	Fuel.	Work begun.	Date of first pumping.	Date of first cultivation.	Cultivated in 1916.	Remarks.
				Acres.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Per ct.*	*Per ct.*	*Inches.*	*Inches.*								*Per ct.*	
3	Gueydon drainage district, subdistricts Nos. 1 and 2	Vermilion	Florence	7,400	0–3	1–3	0	5	330	4	1½	4	1,320	2	1.8	1.5	0.88	1.23	2 54-inch centrifugal	2 Corliss	Return-tube	Oil	1911	1912	1912	20	
5	Avoca drainage district	St. Mary	Morgan City	15,600	0–3	1–7	5	6	165	4	1½	4	1,320		3.6	3.8	2.20	.93	{2 30-inch centrifugal; 1 48-inch centrifugal; 1 72-inch centrifugal	1 Corliss, compound; 1 Lentz	Water-tube	Wood; Oil	1911	1912	1912	30	
6	Upper Terrebonne drainage district	Terrebonne	Houma	4,240	1–5	3–7	0	3	165	4	1	3	1,320		3.6	1.4	70	1.06	{1 24-inch centrifugal; 2 48-inch screw	1-horse-power; 2-horse-power oil-burning		Oil	1912	19.6	1915	10	
9	Lafourche drainage district No. 12, subdistrict No. 4	Lafourche	Raceland	4,240	0–4	3–7	0	5	200				{1,400; 2,000}			1.5	.81	1.69	2 48-inch centrifugal	2 120-horsepower oil-burning		...do	1913	1914	1915	2	
10	Lafourche drainage district No. 12, subdistrict No. 3	...do	...do	2,250	1–3	0–3	0	5	200	4	1½	4	{1,200; 2,000}	2–3	3.0	.8	.50	1.25	2 30-inch centrifugal	2 slide-valve	Return-tube	...do	1908	1910	1910	100	
11	Lafourche drainage district No. 12, subdistrict No. 1	...do	...do	835	0–2	0–3	0	5	200	4	1½	4	{1,200; 2,000}	2–3	3.0	.6	.40	2.15	2 24-inch centrifugal	2 40-horsepower oil-burning		...do	1907	1908	1909	100	
12	Lafourche drainage district No. 12, subdistrict No. 2	...do	...do	940	1–2	0–3	0	5	200	4	1½	3	{1,200; 2,000}	2–3	3.0	1.3	.67	1.91	2 24-inch centrifugal	2 50-horsepower oil-burning		...do	1907	1908	1909	100	
14	Smithport Plantation	...do	Lockport	647	0–2	2–2	0	4	165	4	1	3	5,300	2	2½	3.6	.9	.50	1.50	2 Menge	2 slide-valve	Return-tube	...do	1907	1908	1908	100	
15	Lafourche drainage district No. 13, subdistrict No. 1	...do	...do	2,000	0–2	0–4	0	4	200	4	1	3	{1,200; 2,000}	2	2½	3.0			1.40	2 30-inch centrifugal	2 50-horsepower oil-burning		...do	1914	1915	1919	30	
17	St. Charles municipal drainage district No. 1	St Charles	Paradis	9,860	0–3	1–3	0	5	200	4	1	4	1,320	2	3	3.0	1.2	.66	1.60	2 78-inch screw	2 piston-valve	Return-tube	Wood; Coal	1911	1914	1916		
18	St. Charles drainage district No. 1	...do	...do	2,840	0–2	0–3	0	4	165	4	1	3	1,320	2	2½	3.6	.9	.50	1.42	2 36-inch centrifugal	2 slide-valve	...do	...do	1910	1911	1915	10	
19	Lafourche drainage district No. 6 subdistrict No. 1	Lafourche	Des Allemands	1,880	0–2	0–2	0	3	210	4	1	4	2,000	2	3	2.9	1.0	.34	.95	2 24-inch centrifugal	...do	Marine	...do	1910	1911	1912	55	
23	Delta Farms drainage district No. 4	...do	Larose	2,560	2–3	0–2	3	5	165	4	1	4	{1,320; 2,640}	2–3	3.6	1.0	.66	1.58	2 36-inch centrifugal	do	Return tube	Coal	1913	1914	1915		
24	Delta Farms drainage district No. 1	...do	...do	640	2–3	0–2	3	5	165	4	1	4	2,640	2–3	3.6	.6	.35	1.33	{1 15-inch centrifugal; 1 18-inch centrifugal	2 40-horsepower gasoline		Gas	1910	1911	1911	100	
25	Delta Farms drainage district No. 2	...do	...do	2,720	2–3	0–2	3	5	165	4	1	4	{1,320; 2,640}	2–3	3.6	1.0	.66		1 36-inch centrifugal	1 slide-valve	Return-tube	Coal	1910	1911	1913	22	
26	Delta Farms drainage district No. 3	...do	...do	2,560	2–3	0–2	3	5	165	4	1	4	{1,320; 2,640}	2–3	3.6	1.0	.66	1.58	2 30-inch centrifugal	2 slide-valve	...do	...do	1911	1913	1914	16	
28	Lafourche drainage district No. 9, subdistrict No. 1	...do	Golden Meadow	1,780	0–2	0–2	3–5	5					2,640			.8	.42	1.01	2 24-inch centrifugal	2 50-horsepower oil-burning		Oil	1912	1915			
29	Pontchartrain drainage district, subdistrict No. 1	St. Charles	Labranche	700	0–2	0–3	12	5										1.28	1 24-inch centrifugal	1 slide-valve	Return-tube	Coal	1913	1914	1914	50	
30	Kenner drainage district	Jefferson	Kenner	2,100	0–1	1–3	6	7								2.1	1.17	1.35	2 30-inch centrifugal	2 slide-valve	do	Wood	1912	1914			
31	Willswood Plantation	...do	Waggamon	2,600	0–4	2–9	0	8	{100; 400}	3	1½	3	2,400	2	2.4	2.0	42	1.60	{1 rotary, 1 Menge; 1 36-inch centrifugal	2 automatic; 1 slide-valve	Water-tube	Oil	1896	1897	1897	100	
32	New Orleans Netherlands Co. drainage district	St. Charles	New Orleans	2,120	1–3	1–3	0	4	200	4	1	4		2–3	3.0	1.2	.63	1.75	{1 24-inch centrifugal; 2 30-inch centrifugal	3 50-horsepower oil-burning		...do	1912	1913	1914		
33	Jefferson drainage district No. 3	Jefferson	Lafitte	5,000	0–4	1–3	3.0	5	220	4	1	4	2,000	2–3	2.7	1.1	.60	1.44	2 48-inch centrifugal	2 Corliss	Return-tube	...do	1911	1913	1914	15	
36	N. O. Lake Shore Land Co.	Orleans	New Orleans	6,950	0–12	1–3	6.0	10	165	5	1	5	1,320	3–4	3.6	1.2	.97	1.81	3 48-inch centrifugal	1 Corliss, 2 electric motors	Water-tube	Coal	{1908; 1913}	{1908; 1913}	1909	85	
37	Plaquemines-Jefferson drainage district	{Plaquemines; Jefferson}	...do	37,750	0–3	1–9	0	4										1.04	{1 48-inch and 1 72-inch centrifugal	5 Corliss, compound	...do		1912	1915		20	{Part of land cultivated before present improvement.
38	Reclamation district No. 1	Plaquemines	Poydras	2,500	3–4	0–1	6.5	7	165	3	1	3	660	2	3.6	1.5	.90	1.17	1 24-inch and 1 36-inch centrifugal	2 slide-valve	Return-tube	Coal	1910	1912	1912	30	
42	Bayou Terre Aux Breuf drainage district, subdistrict C	St. Bernard	Alluvial City	7,000	0–4	0–3	10.0	6										1.03	2 48-inch centrifugal	2 Corliss			1913				
43	Venice drainage district	Plaquemines	Venice	1,100	0–3	1–4	7.0	5	{100; 200}	3	1	3	2,000	2	4.0	1.7	.90	2.55	2 30-inch centrifugal	2 slide-valve	Return-tube	Coal	1914	1915	1915	20	Do.
44	Buras drainage district	...do	Buras	2,358	0–2	1.5–5	7.7	6								2.0	1.00	1.38	{1 48-inch screw; 1 36-inch screw	1 100-horsepower, 1 50-horsepower oil-burning		Oil	Under contract.			25	
1	Jefferson drainage district No. 4, subdistrict No. 4	Jefferson	New Orleans	1,800	0–12	0–2	6.0	6								5	.28	1.56	2 30-inch screw	2 60-horsepower oil-burning		...do	1915	1916			
22	Lafourche drainage district No. 20, subdistrict No. 1	Lafourche	Cut Off	2,500	2–3	2	4.5	7	165	4	2	3	1,320		3.6	1.1	.66	1.62	2 36-inch screw	2 125-horsepower oil-burning		...do	1916				Under construction.

[1] For locations and status of districts see figure 1.

The advantages of the large district over the small one are:

(1) Low cost of levees per acre of protected land;

(2) Possibility of using natural ridges in part for levees;

(3) Possibility of using natural bayous and lakes as part of the interior drainage system;

(4) Use of efficient machinery due to more continuous operation of the pumping plant;

(5) Low first cost, per unit of area, of pumping plant due to centralization of equipment and smaller relative capacity;

(6) Low unit operating charges on pumping plant.

The benefit of low lifts on the smaller districts is offset by the advantages in using more efficient machinery for the high lifts on larger districts and the less cost per acre of machinery. Unit labor charges for plant operation also are much less on the larger districts. Although the haul to water transportation on large districts is necessarily greater, with larger interests involved, good roads can be built and maintained economically. Since the cost of levee per acre of reclaimed lands is so much less on a larger district, a better class of levee can be constructed, resulting in an increased margin of safety. While the small district can take advantage of natural ridges at times, this usually is possible only on one or two sides, and only in rare cases can the small district include natural bayous and lakes as reservoirs. The advantages, in the case of the small district, of the small capital involved and the earlier return on the investment may be offset easily by the increased cost per acre for construction of levees, canals, and pumping plant. The operation and maintenance charges, which are a perpetual tax on the land, also are higher on the small district, and from the standpoint of the individual owner and cultivator of the land the advantage is all with the large district.

Just what is the most economical size of district has not yet been determined; it is a matter that is greatly affected by local conditions. However, it is the consensus of opinion among engineers engaged in this work that districts containing less than 2,000 acres are not at all desirable. An area of about 5,000 acres has been found very satisfactory under average conditions. Where large lakes and bayous can be included as reservoirs and drainage channels and natural ridges can be taken advantage of for levees, a district well may be much larger than 5,000 acres.

LEVEES.

The location of a levee influences its design, construction, and maintenance, as well as its usefulness to the district. Unlike levees along our rivers, those along the average reclamation district in this section have not been located according to the topographic conditions, but rather according to property or land lines. This has usually resulted in regularly shaped districts and minimum length of levee for area inclosed; but the cost of construction and maintenance per unit of length has often been much greater than if some attention had been paid to topography. Throughout most of the wet prairie there are winding bayous that have along them solid ridges of silt that average from 1½ to 2 feet above general ground surface. In other places the bayous are filled in entirely, and there have been left ridges of silt having widths of from 200 to perhaps 1,200 feet, with the usual elevation of 2 feet. If the levee be located on a solid ridge, the material will be more stable and impervious and the levee can be made of less cross-sectional area than would be necessary if it were located in the soft prairie. Construction, also, will be easier and cheaper and the expense of maintenance much less. Where levees are to be

built to protect areas of marsh land on the immediate coast line, a strip of land at least a quarter of a mile wide should be left as a foreshore to break the force of the wave. Where the exposure is particularly great, this strip of land should be wider.

If the levee be located on firm land and the land outside the levee never is flooded for more than a few days, it will, in some cases, be advisable to dig the canal from which material is taken for the levee on the inside of the district and to utilize this canal as a drainage channel. In such cases the berm should be especially wide, at least 20 feet. In general, this type of construction is not recommended. If the levee canal be placed on the outside of the district it can be utilized for navigation.

The design of the levee will depend largely on local conditions. Its top should be from 2 to 4 feet above the highest stages of water in the surrounding lakes and bayous, depending on the area of land protected and the probability of previous high-water marks being exceeded. Where the water to be kept out is due to storm tides in the Gulf, the height of the levee should be determined only after very careful investigation of all surrounding conditions has been made and the probable highest stage estimated, taking into consideration the local conditions as outlined under the section on Tidal Overflow. If the levee is located in an exposed locality its top should be about 4 feet above the estimated highest water. A minimum height of about 4 feet should be used through the soft prairie section, as anything less is not likely to prevent seepage satisfactorily; for when located on a ridge the water will stand against a levee only for short periods, while if located in a soft prairie the water will be in continuous contact with the lower foot or two of the levee. In places exposed to strong wave action the height should be sufficient to provide for the break of the waves; in addition, some provision should be made for protecting the levees from their erosive action. This protection could be secured by planting willows some distance in front of the levee.

Where the levee is located on a ridge the top width may safely be made 4 feet, with side slopes 2 to 1. A levee of this type is often built with wheelbarrows, and although the unit cost for this method is quite high, being about 18 cents per cubic yard, the total cost is considerably less than if the work were done with the usual floating dredge. Yard for yard, the dredge would, of course, handle the material much cheaper, but the excavation would be more than would be necessary for the levee. This objection would be overcome if the dredge were building a levee along the bank of a bayou of sufficient depth to float the machine, or if a reservoir canal were being excavated within the district, the waste bank to be used as a levee.

Where the levee is located in the soft prairie the top width should average about 6 feet. The side slopes should be about 3 to 1; in fact, if the material is very soft it will not take a much steeper slope than this during construction. As the material always becomes more stable after being placed in the levee, no trouble should be expected from slides after it begins to dry in place.

The berm along the base should be at least 15 feet wide. Where the soil is exceptionally soft this should be made as much wider as practicable, at least 20 feet. The width of berm will of course depend somewhat upon the nature of the machinery used in construction.

Some type of floating dredge should be used in the construction of most levees. In heavily timbered sections, or where old submerged stumps are numerous, the dipper dredge will work to the best advantage; but in the open, grass-covered prairie the orange-peel-bucket dredge has many advantages.

Owing to the longer boom and narrower hull, the latter type of dredge is able to leave a wider berm along the toe of the levee. It also is better able to sort the material placed in the base of the levee; for the top layer of muck can first be taken out of the canal, and then the silt underneath, while the dipper dredge will usually cut up through both the silt and the muck and mix them. The levee should usually be constructed in several layers, for both the base and the material are likely to be so soft that subsidence will be too great if a height of more than a few feet is attempted. This yielding of the base will often cause the side of the canal to cave, especially if the berm be small.

The total subsidence and shrinkage of the material in the levees often amounts to 50 per cent, and in special cases is as great as 80 per cent of the bulk of the material, as measured in excavation. Practically all of the subsidence and a part of the shrinkage takes place during construction, so that the remaining change in height can be taken care of by maintenance. When a large percentage of muck is placed in the levee the shrinkage will be great for a number of years, due to the decay of the vegetable material in the muck.

The orange-peel bucket is especially suitable for placing several layers in a levee. After a canal is once cut in the soft prairie a considerable depth of soft mud that makes very poor levee material will be in the bottom. The dipper dredge, when working in such a canal, will place a large percentage of soft mud in the levee; while an orange-peel bucket, when dropped forcibly, will penetrate the undisturbed silt below and fill with it, the soft mud running off when the bucket is raised.

If the site of the levee is along a solid ridge above ordinary water level, no special precautions need be taken to prevent seepage, although all stumps and logs should be removed from the site and a shallow ditch should be cut to insure a perfect bond between the ridge and the levee. On the other hand, if the levee is through very soft prairie, the material dropped from the dredge will penetrate the muck and form a good bond with the underlying silt. It is on the portions where the muck is thick and turfy in character that particular pains must be taken. A ditch cut along the center line of the levee before the dredge starts working is of no special benefit, as the material placed back in the ditch by the dredge will be largely muck, although it is true that this treatment will break the continuity of the muck and help to cut out a portion of the seepage. A better plan is to wait until the first layer of material has been placed by the dredge and then cut a ditch along the toe of the slope of the levee opposite the dredge and refill it with impervious silt dredged from the bottom of the canal. This will insure a good bonding of the material and is a necessary part of the construction. At times old muck-filled bayous will be encountered which must be closed with levees. In such cases the quickest, and quite often the cheapest, way to insure that the levee hold its grade line is to drive two rows of sheet piling across the bayou at the proper spacing. These rows should be tied together with rods and the fill made between them.

The average unit price for dredge-built levees, where the material is measured in excavation, has been from 6 to 8 cents per cubic yard, depending on the amount of timber and stumps encountered. Large amounts of such work have been done at an actual cost, to the owners of the dredge, of less than 3 cents per cubic yard. Since it requires from one and one-half to three times as much material in excavation as finally appears in the settled embankment, the contract price would vary from 10 to 25 cents per cubic yard of such embankment.

If the levee is to be brought to a regular cross section by hand or machine work, a small additional charge should be made. In general, however, the levees, as built, have not been surfaced after the dredge work is finished,

although it would be better if the levee were smoothed off, seeded to Bermuda grass, and pastured. This will aid in closing up the cracks that form through the gradual shrinking of the material. In certain cases it may become necessary to plow and harrow the levee in order to close up these cracks. If this is not done, and if a rapid rise of the water outside the district occurs after a prolonged dry period, the seepage through the body of the levee will be very great. In certain cases this seepage through shrinkage cracks has overtaxed the capacity of the pumping plant. The grazing of the levee provides a cheap and profitable method of maintenance and will discourage the action of burrowing animals.

INTERIOR DITCH SYSTEMS.

Rainfall and seepage cause an accumulation of water within the levee district that must be collected by a system of ditches and canals, led to a central point and discharged over the levee by means of pumps. Numerous arrangements of ditch systems have been used with varying degrees of success, depending on how well the work was executed and maintained. The best of present practice is to make this system consist of small ditches which can be cut and maintained by hand, discharging into reasonably large canals which can be cut and maintained by means of a dredge. The use of intermediate-sized ditches, say, 6 to 8 feet wide and 5 or 6 feet deep, has not proved successful on these districts. Since such ditches are free from water most of the time, grass grows very readily in the bottoms. Moreover, they are too large to be cleaned by hand easily and are too small to allow the use of a dredge.

Field Ditches.

On the typical wet-prairie reclamation district the land is so nearly level that a regular layout of field ditches is desirable rather than a location designed to take advantage of such slight surface slopes as may exist. The ditches should be cut in parallel lines and at such a spacing as will correspond with the character of the land. As shown in Table I, the spacing of ditches has varied from 100 to 330 feet. The degree of drainage required in these soils depends somewhat on the crop. Where rice is grown, a spacing of 330 feet has proved ample for soils in southwestern Louisiana. Where very valuable truck crops are to be grown, a spacing even less than 100 feet might be required. In general, a spacing of about 200 feet has been found satisfactory for general field crops, such as corn and sugar cane. As the lands are cultivated and compacted, and the loose vegetable material in the soil decays, a spacing of less than 200 feet may be necessary. A ditch 4 feet deep, 4 feet wide at the top, and about 1½ feet wide at the bottom has been found to be the most economical to cut and maintain by hand. Ditches of this size are of ample capacity, unless they become choked with weeds or are required to bring the water too far. Since the land is practically flat, flow in such a ditch is caused only by the piling up of the water in the upper end of the ditch. If the ditch is too long, this will bring the water too close to the surface of the land. In practice it has been found that in flat land such ditches can be made one-fourth mile long with good results, and they have worked fairly well in a few cases at a length of one-half mile. However, this latter length is not recommended, as the ditch must be maintained in almost perfect condition in order to give satisfactory drainage. In most cases where the small field ditches are one-half mile long they have not proved satisfactory.

While this type of ditch can be cut in this section with hand labor for from 5 to 7 cents per cubic yard, a large proportion of the work has been done with

machinery. Where a large body of land is to be ditched rapidly a more rapid means than handwork is desirable, even where the cost by machinery is about the same or even greater. Wheel excavators mounted on apron traction and driven by gasoline engines have been very successful. They cut a very satisfactory ditch and place the excavated material farther back from the ditch than is possible by hand. Where there is much timber or stumps these machines can not be used. Machines can not be used on the softer prairies until the land has been surface drained for some months and become somewhat solid. A common practice has been to cut ditches at a spacing of about 1,000 feet by hand, the resulting drainage making it possible to use the machine soon afterwards to cut the remaining ditches. Hundreds of miles of ditch have been cut with excavators at from 3 to 6 cents per cubic yard. In one case ditches were cut with a heavy wooden-framed plow, especially built for the purpose, drawn across the strips of land between the reservoir canals by cables and pulling engines mounted on barges. These ditches were cut as soon as the pumps were started and the water drawn off the surface, which was many months before the land would have supported the ordinary wheel excavator.

Ditches in this class of land require much attention for the first year or two after cutting. A soft mud from the banks collects in the bottom, and rapidly growing weeds and grasses impede the flow of the water and aid in the silting process. The soil shrinks considerably after it is drained and cultivated, and the effective depth is soon reduced below that required. This clean-out work is done best by hand, but even that is an unsatisfactory process, the mud being too thick to run out of the ditch, but also too thin to pick up with a shovel. By selecting a time of scant rainfall, when the bottom of the ditch is nearly dry, it can be cleaned the most effectively. It is necessary to cut the grass and weeds in these ditches about twice a year, and for the first few years after first cutting they will have to be cleared of soft mud at least once a year, taking out about a cubic foot of material per linear foot. After perhaps four years, cleaning will be necessary only once in two years. The cost of maintaining these open field ditches would more than pay the interest on the extra investment necessary to tile-drain the land. In addition there would be a large saving in land and a greater convenience in farming operations. While a shallow open ditch would still be necessary to carry away the run-off from heavy rainfalls, the action of a well-laid tile drain would be much more uniform in taking away the ground water than would an open ditch, which is in good condition only for a few weeks after it is cleared of grass and weeds. It would not be possible to lay tile drains in the newly reclaimed lands, but after they have become firm a large percentage of the open ditches should be replaced by tile drains.

Reservoir Canals.

The primary requisite of the reservoir canals is that they give sufficient outlet to the field ditches. To do this they must be spaced not much more than a half mile apart and preferably should be located in parallel lines. Without too much sacrifice of regularity they should be located in the lowest ground, so that the flow of the water from the field ditch will be facilitated as much as possible. The arrangement of canals also should be such that the water in flowing from the farthest corner of the district to the pumping plant travels as short a distance as practicable.

The reservoir canal serves a two-fold purpose: (1) To take the water from the small field ditches and carry it to the pumping plant, and (2) to store up the dry-weather flow of the ditches so that the pumping plant will not need to be operated so frequently. When some of the districts examined were first

reclaimed the interior canals were too small and too shallow either to carry the water rapidly to the pumping plant or to store up water for pumping. As a result it was necessary to operate the pumping plant for a few hours almost every day, and at times of heavy rainfall the portions of the canals remote from the pumping plant were too full of water to give outlet to the ditches. These canals ultimately were made wider and deeper.

Since the land is flat, flow in the canals can result only from a piling up of water in one portion or from the lowering of the water by the action of the pumps. If the canals are small, the velocity of the water in them must be high in order to bring water to the pumps; this will mean a large surface slope and a large difference in the elevation as between the water surface at the pumps and that in the remote portions of the district. Although immediately after very heavy precipitation the water may safely stand level with the lowest land for several hours, the canals should be of such cross section that they will be able to deliver enough water to allow the pumps to be operated when the water stands at least 4 feet below the surface of the land. The surface slope of the water in a canal of this size necessarily will be small; it should be between 0.2 and 0.4 feet per mile. The minimum depth for such canals is 7 feet, and the depth should increase gradually toward the pumping plant so that the bottom shall have a slope at least as great as that of the water surface. This will allow a depth of 1 or 2 feet of water to be maintained in the canals at all times, which is sufficient to discourage the growth of weeds and grass. Experience on such reclamation districts has shown that shallow canals become choked with weeds and grass very quickly and require frequent cleaning.

Reservoir canals have been excavated with a number of types of dredge. Owing to the soft nature of the land a floating dredge is always required. Where there is considerable standing timber and sunken logs and stumps, a dipper dredge is the best machine for cutting the canals—at least for taking out the top 4 or 5 feet. It has been found best to cut the canals in two layers, allowing the banks and the material excavated the first time over to solidify before placing an additional load on them.

Where the prairie is free from stumps, or where the stumps have been taken out of the way with a dipper dredge, a long-boom, gravity-swing, orange-peel bucket dredge is a very satisfactory means of cutting such canals. This disturbs the material much less than does a dipper dredge, and the canal cut with the orange-peel bucket will be much freer of soft mud than one cut with the dipper dredge. In any case, such dredges should be equipped with vertical spuds instead of bank spuds, which have caused serious caving on all canals where they have been used in the soft prairie land. The berms between the side of the canal and the spoil bank should be at least 10 feet and preferably 15.

The hydraulic dredge is perhaps the most satisfactory means of cutting interior canals. The top 4 feet might first be taken off with a dipper dredge, thus forming low retaining walls to keep the material placed by the hydraulic dredge from running back into the canal. Such canals will be free from soft mud, and the side slopes can readily be controlled. While the side slopes of the canals are limited more or less by the character of the excavating machinery, if operated with care a dipper dredge can easily give a slope of $\frac{1}{2}$ to 1 on the canals. If the material is placed well back from the banks this slope has been found to be satisfactory. The excavating of such canals has been done by dredges owned by the district at a cost per cubic yard of from 3 to 5 cents. The work has frequently been contracted for at from 6 to 8 cents.

PUMPING PLANT.

The drainage of low-lying wet lands by means of pumps is described in a publication of this office.[1] The bulletin discusses the general practice of land drainage by means of pumps and deals especially with conditions in the upper Mississippi Valley. The general nature of this method of drainage in southern Louisiana is much the same as described in that bulletin, but there are many differences in detail that deserve mention. These differences affect chiefly the capacity and operation of the pumping plant.

Necessary Capacity of Plant.

The general method of operation of plant in southern Louisiana is far different from that in the northern latitude, so before discussing in detail such rainfall and run-off records as are available it might be well to describe the usual method of operation. In southern Louisiana farming operations are conducted every month in the year. While general field crops are growing only about 9 or 10 months, the field must be kept sufficiently well drained to permit cultivation at any time. The bulk of the heavy plowing is done during what are ordinarily called the winter months. The need of the pumps, therefore, is more or less continuous—that is, the run-off at any time of the year must be taken out promptly.

During the first few years after construction the maintenance charges on reservoir canals are quite high. A certain amount of bank caving occurs, and a large quantity of semifluid mud comes in through the field ditches from the soft land. The velocity of flow in the canals is not sufficient to transport any appreciable amount of this soft mud to the pumping plant. Unless the water is lowered very slowly when the pumps are first started, the tendency of the soft subsoil to flow into the canals will become apparent. In one case where the water was lowered rapidly the canal became several feet narrower and shallower within a week or two. While in this case the spoil banks were too close to the sides of the canal, and no doubt contributed to the rapid shrinkage of section, the shrinkage was due mostly to a rapid lowering of the water. Canals cut by hydraulic dredge will not be so susceptible to shrinkage, as the weight of the excavated material does not rest on the banks.

This rapid filling of the canals when the land is first drained makes it good practice to excavate the canal somewhat larger than is desired for the permanent section. If this be done, the canal will not require cleaning until the land has had time to solidify and the soft mud has stopped coming in from the small ditches. While the canal can then be cleaned with either a floating dipper or orange-peel-bucket dredge, the best way is by the use of a hydraulic dredge. All overhanging and unstable banks should be sloped by hand in advance of the dredge work; this material then can be taken out along with the soft material in the canal bottom. The chief objection to the use of the hydraulic dredge for this clean-out work is the effect of the water and soft mud on the growing crops along the canal. To avoid this damage a small excavator mounted on skids along the side of the canal has been used very successfully. By keeping the canal practically empty of water, the soft mud will solidify enough to allow it to be taken out by means of either an orange-peel or clam-shell bucket handled by the excavator mounted on the bank. If this cleaning of the canals is done after they have been cut and the land well drained for three or four years, further cleaning will not be necessary for a long term of years. Because of

[1] U. S. Dept. Agr., Department Bulletin 304, contributed by Office of Public Roads and Rural Eng.

the long growing season various kinds of water plants grow in the water and float on the surface. Such plants will have to be removed about twice a year, or they will impede the flow of the water seriously.

The influence of evaporation at different seasons of the year causes a great variation in the manner of operating the pumps. A heavy rainfall in summer necessitates continuous operation of the pumps for a period sufficient to empty the canals and ditches. The water that will continue to run out of the lateral ditches will often be more than balanced by the evaporation, so that it will not be necessary to start the plant again until another period of heavy precipitation occurs. Small local rains in summer in all likelihood will pass unnoticed. During the winter months a heavy precipitation necessitates a relatively longer period of pumping than in summer. Two or three days after the canals have been emptied the ground-water drainage entering through the lateral ditches will make it necessary, owing to lack of evaporation, to operate the plant for a few hours, and after an interval of about 10 days it will be necessary to do some more pumping, although no precipitation may have occurred in the intervening period. If the reservoir capacity of the canals be small, the operation of the pumping plant will be still more intermittent. If the plant be divided into two or more units, one unit only may be operated for the dry-weather run-off. The total time of pump operation during the year rarely exceeds 45 days of 24 hours each, and often drops to as low as 15 days. The total number of days on which the pumps are operated averages about 70.

In southern Louisiana most of the pumping plants so far installed have a theoretical capacity of at least 1 inch, and many of them 1½ inches, in depth of water over the inclosed area in 24 hours. The 1-inch run-off is equivalent to approximately 27 second-feet per square mile of area, or 0.042 second-foot per acre.

The necessary capacity of a pumping plant depends on the size and slope of the district to be drained, the depth and nature of the muck, the available storage capacity of canals and ditches, the system of lateral drains used, the method of operation of the plant, the character of the crops raised, and the amount and distribution of the rainfall. The proper allowance to be made for each of these factors can be determined only as the result of careful and complete observations in the field. Not only should the results for each district examined be worked out carefully, but the investigations should include a sufficiently large number of typical districts and should continue for such a length of time as to make the results of general application. Some of the above factors have been quite closely investigated over a few districts, and all of them have been covered in a general way. While the results obtained are not final, and the investigations still are being carried on, these details will be discussed in the light of such investigations as have been made.

In planning gravity drainage districts it is customary gradually to decrease the run-off coefficient as the size of the district increases. With one exception the variation in size of the district in this section is as yet not great; therefore not much attention need be given this feature. In the summer, when rains are almost purely local, the larger district is not so likely to receive rains over its whole surface as is the smaller. However, the rains that tax the pumping plant most heavily occur in the spring of the year and are general in character.

The variation in surface elevation on the average district is slight, but where the district fronts on a ridge having an elevation above the prairie land of from 8 to 12 feet it has been noticed that the lower lands become flooded at times of heavy rainfall, even though the pumping plant capacity on the district in question be larger than that sufficient for the flat lands. This flooding of the lower

lands can be partly overcome by a proper design of the various parts of the collecting system. By careful location of gravity outlet ditches this drainage water from the higher lands can be entirely diverted in some cases.

The character and depth of the layer of muck overlying the subsoil on these lands have a large influence on the run-off. The muck absorbs water very readily, and if well drained to a depth of 3 feet its storage capacity is about 8 inches. When the land is first drained this muck will absorb water nearly as fast as the heaviest rate of precipitation, but as it decays and compacts both the storage capacity and the rate of absorption decrease very rapidly. A gradual increase in the rate of run-off then must be expected.

The effect of reservoir capacity has already been discussed. However, it might be well to point out that increase of reservoir capacity does not decrease the amount of pumping to be done, but simply acts to decrease the time of flooding in case the run-off overtaxes the capacity of the plant.

Deep lateral drainage acts to decrease the intensity of run-off. If such laterals be lines of tile, the rate of run-off will be decreased still further, for practically all water must then pass downward through the soil and out through the tile before it can reach the canal, while in the case of open field ditches most of the water can flow over the surface to the ditch and thus directly into the canal. Especially will this effect be noticed as the muck gradually loses its power of rapid absorption.

If the pumping plant be designed to operate continuously, its capacity may be less than that of a plant intended for day use only. As mentioned previously, there is need of the plant at all times of the year. The fact that the water is always pumped out promptly and all reservoir capacity is quickly available makes a smaller plant capacity practicable.

While a knowledge of the total yearly and monthly amounts of rainfall, either maximum or average, is important in determining the probable total amount of water to be pumped each year or month, the intensity of rainfall during storm periods extending over only a few days is the factor that fixes the necessary capacity. As the run-off from a given rainfall will depend largely on the condition of the soil before the rain occurred, a determination has been made of the proportion of storms that occur when the land is wet, by examining the records of rainfall and pumping kept since June, 1909, on a number of typical districts in southern Louisiana. Of all the storms exceeding 2 inches and under 4, in 24 hours, 64 per cent occurred on a wet and 36 per cent on a dry surface; for the storms exceeding 4 inches in 24 hours the percentages are 54 and 46 per cent, respectively. Of course, the storage capacity of the land influences the rate of run-off from the small storms relatively much more than it does that of the large ones. However, an examination of the daily rainfall and pumping records shows that the heavy rains on a dry soil do not make a very heavy demand on the pumping plant. It is believed that on this account a reduction of about 30 per cent in the average frequency of storms as tabulated on page — could safely be made and that the resulting figure would be the proper one to use when estimating how often a storm would occur on a wet soil.[1]

Knowing the character of the operations to be conducted on the land of a given district, a decision can then be reached as to the heaviest storm for which provision must be made. On a district where staple crops are to be raised it would be a matter of economy to allow a certain amount of flooding oftener than would be permissible on land where high-priced truck crops are to be raised, while in residence districts it would be desirable to prevent all sur-

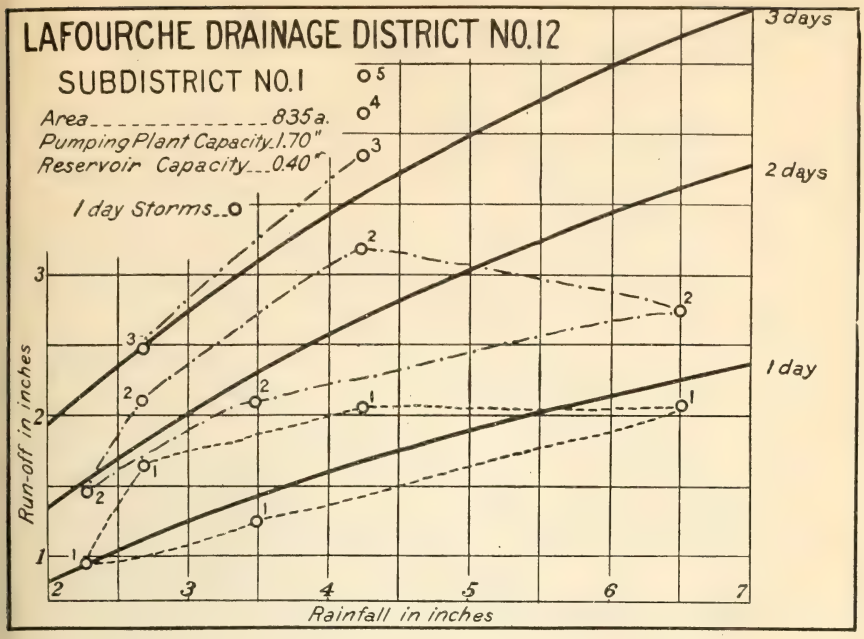
[1] For a full discussion of the relation between rainfall and run-off in southern Louisiana, see Journal of Agricultural Research, Vol. XI, No. 6, Nov. 5, 1917.

face flooding. In addition to the damage to crops due to flooding there are other factors to be considered, such as inconvenience to residents and the possible depressing influence on land values of floodings occurring even at infrequent intervals.

A study has been made of the results of all such heavy storms as occurred on the districts where records have been kept. For almost the entire period covered by the record at each pumping plant, hourly readings have been made of the stage of water in the main reservoir canals during the operation of the pumps. Also, the amounts of water stored in the main reservoir canals at the different levels have been calculated. By this means the amounts pumped per day during the heavy storms have been so adjusted for a number of typical storms on each district, that the final results represent approximately the quantity of water that would have been removed had the pumps taken the water as fast as it entered the main reservoir canals; in other words, these results represent approximately the true run-off for the storms selected. With the exception of a very few heavy storms, only such were selected as occurred when the land in the district was saturated, or at least fairly wet. Owing to the differences in the degree of wetness of the land, the intensity of the rainfall, the time of the year, the condition of the drainage channels, etc., the results for a given district are not uniform. However, to aid in judging what run-off would occur under average conditions the results are shown in the form of curves (figs. 11 to 15). The amounts of run-off, in inches of depth, for one, two, three, and four day periods have been plotted as ordinates and the rainfall, in inches, for each storm as abscissas. Dotted lines have been drawn through the points representing the run-off for each period. The curves have been drawn as far as possible to average these groups of points, or zones, and to conform to each other at the same time. On each set of curves is shown the area of the district, the average capacity of the pumping plant per 24 hours (this will be somewhat different from that shown in Table II as the latter is the maximum capacity), and the storage capacity of the main drainage channels between the surface and a level 5 feet below. In the case of the New Orleans Land Co. tract the water discharges by gravity as fast as it enters the main outfall canal, so no figures for pumping plant and reservoir capacity are given.

It is evident that the effect on the run-off of a change in the capacity of the pumping plant can not all be accounted for by the change of level of the water in the main reservoir canals, as a greater slope and velocity if the water obtains in the drainage channels when a larger plant is operating. This condition is illustrated in the curves, where in general a higher rate of run-off per acre is shown on districts having the larger pumping plants. The effect extends to the small field ditches which have considerable storage capacity, the amount of which it is not practicable to estimate.

In using these curves to estimate the run-off likely to be caused by an assumed storm on an assumed district, the curve should be selected for the district which resembles the assumed district in area, pumping, and reservoir capacities, and other general conditions. The curves of course must be considered merely as representing general tendencies rather than definite values. However, by their use it should be possible to approximate the relative and combined capacities of pumping plant and reservoir canals necessary to remove the run-off caused by a given rainfall. For example, suppose it is desired to determine the required reservoir capacity for a district resembling in a general way the Smithport Planting Co. tract, where the capacity of the pumping plant is to be 1 inch. For a storm of 5 inches in 24 hours the curve for the Smithport Planting Co. tract shows that 0.4 inch would be left as surplus in the reservoir



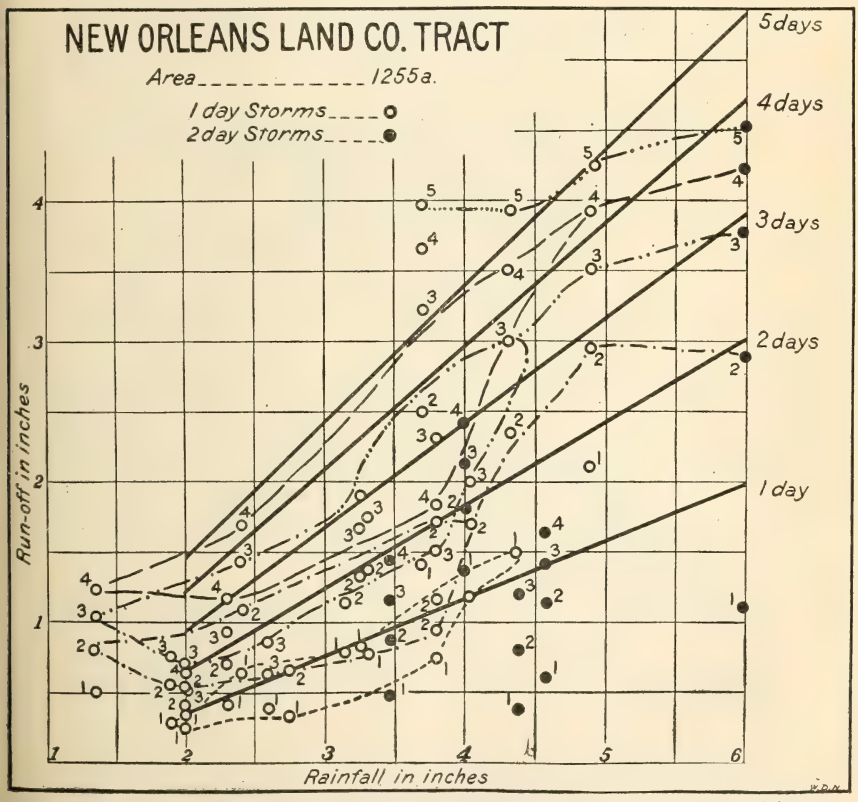
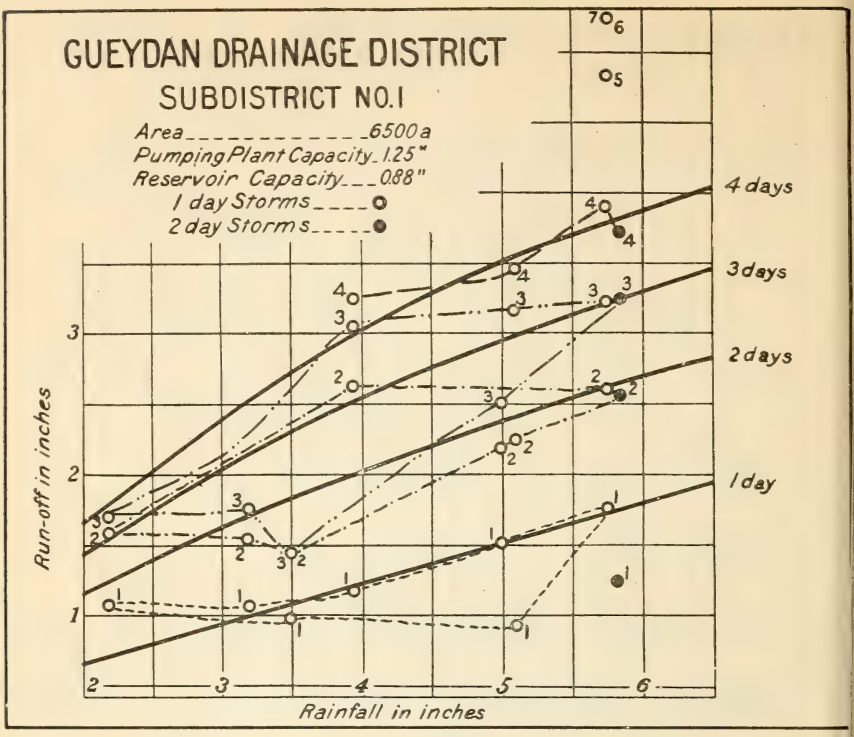


FIG. 11.—Probable actual run-off from drainage districts in southern Louisiana.



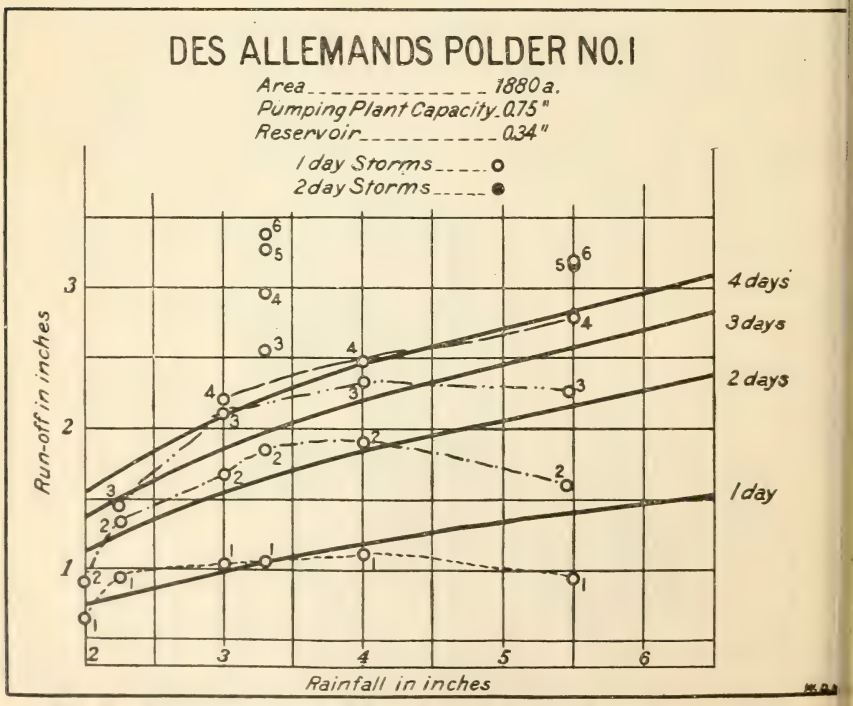
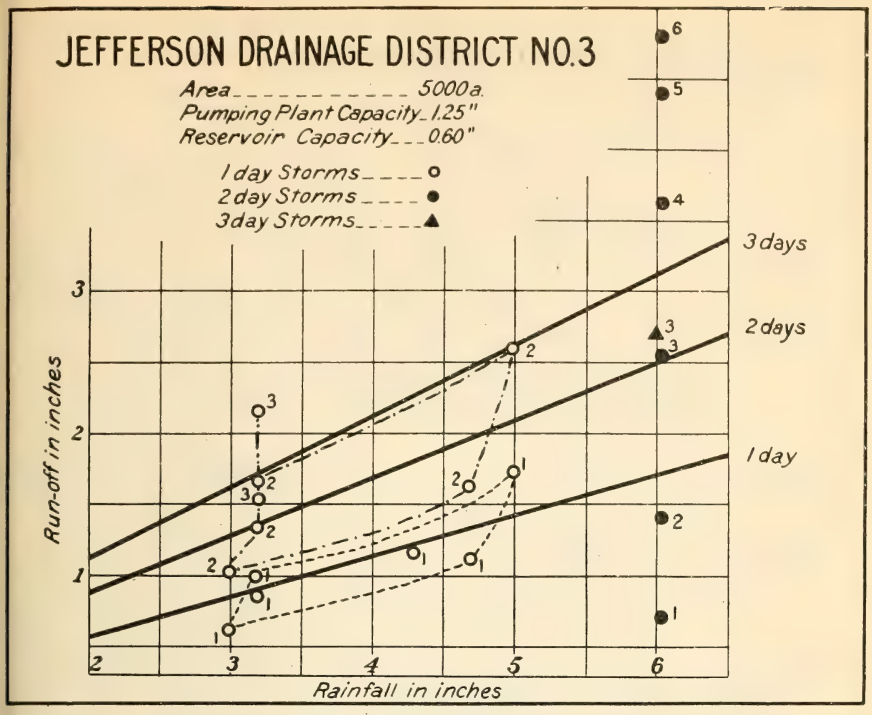


FIG. 12.—Probable actual run-off from drainage districts in southern Louisiana.



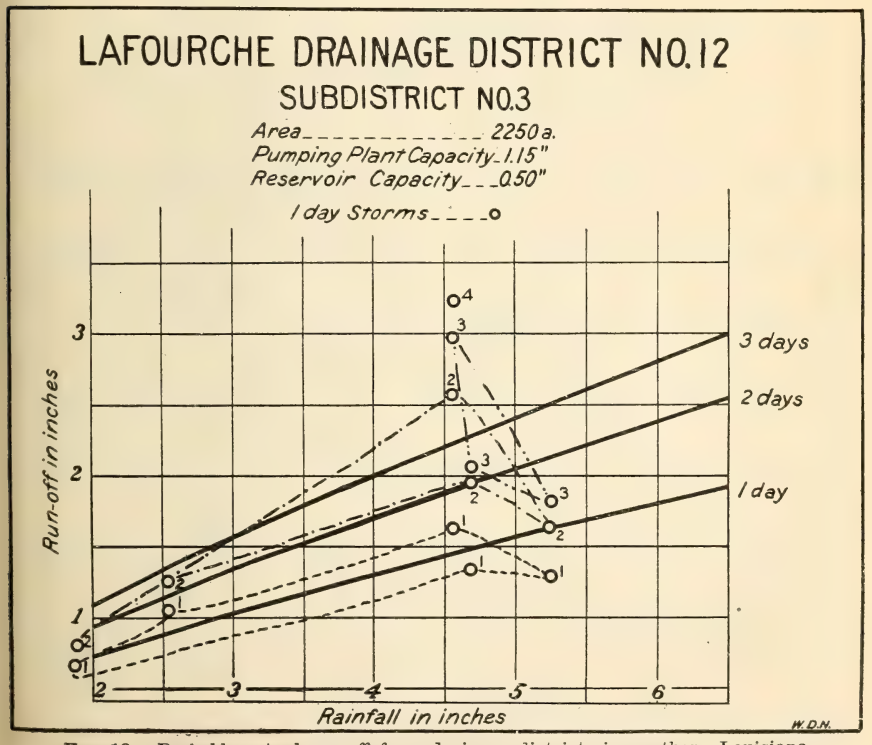
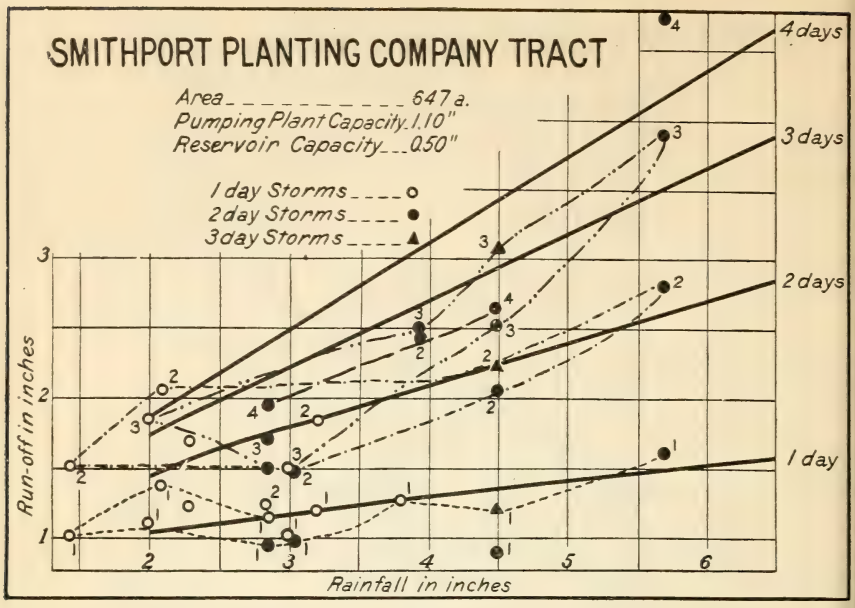


FIG. 13.—Probable actual run-off from drainage districts in southern Louisiana.



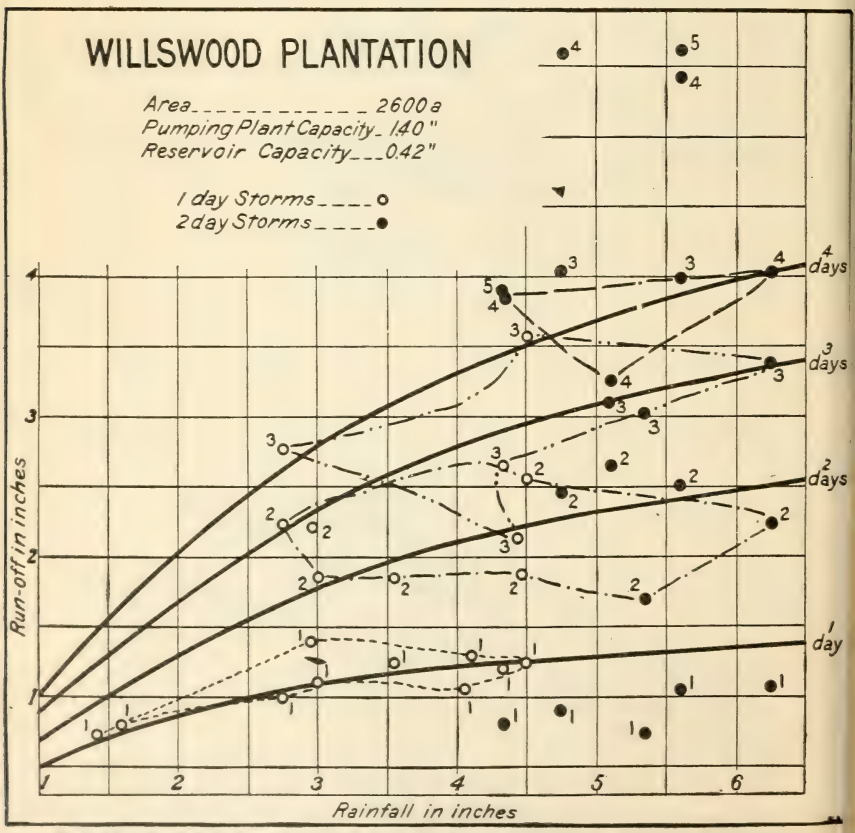


FIG. 14.—Probable actual run-off from drainage districts in southern Louisiana.

canals at the end of the first 24 hours. At the end of the second 24 hours the surplus still would be 0.4 inch, while at the end of the third day it would have been reduced to 0.2 inch. Before the end of the fourth day the pumping plant would have lowered the water to a level 5 feet below the surface of the land. Since the greatest amount of surplus water left in the reservoir at any time was 0.4 inch, a reservoir having this capacity would be able to prevent flooding, provided the run-off was as shown on the Smithport curves. By making other assumptions as to capacity of plant, the corresponding capacity of reservoir can be approximated. Then by calculating the cost of each pumping plant and each reservoir, using current prices for material and earthwork, the cheapest combination can be determined.

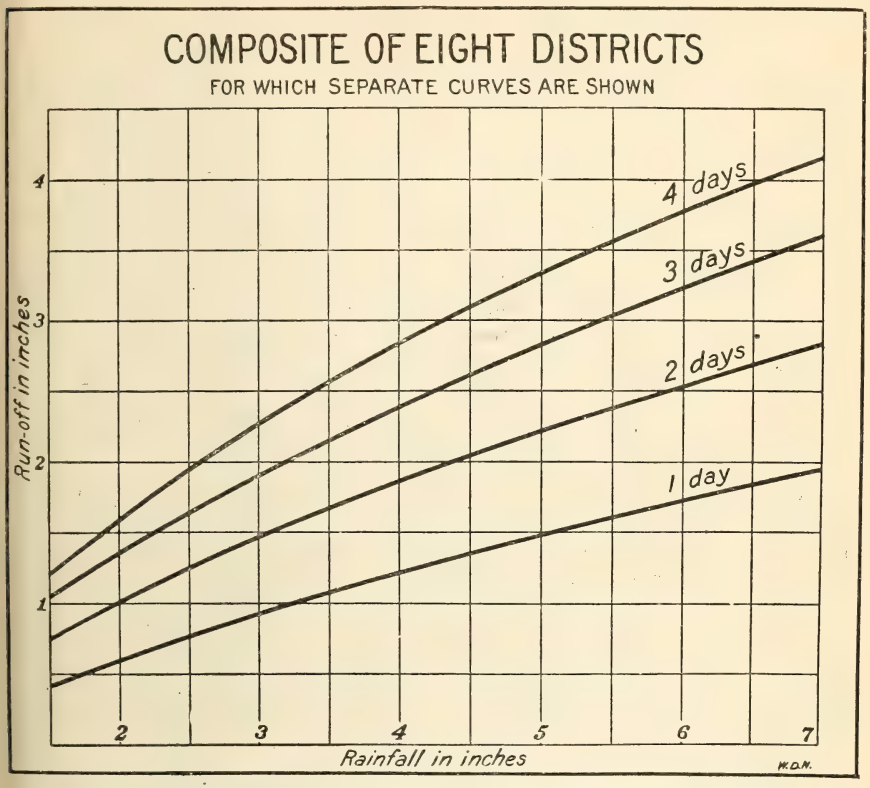


Fig. 15.—Probable actual run-off from drainage districts in southern Louisiana.

In general, a system of reservoir canals having the proper depth and width to give good drainage to the entire area, and allowing the use of average-sized dredges to construct them, will have a reservoir capacity of about 0.5 inch in depth over the entire tract. This size will be ample to bring the water to the pumping plant fast enough to secure continuous operation until the water is lowered sufficiently in the portion of the canals most remote from the plant. While a further increase in the size of the reservoir will allow a certain reduction in the capacity of the pumping plant, the combined cost will usually be greater with this increase of reservoir. In other words, after a certain point is reached it is cheaper to increase the capacity of the pumping plant than it is to incease the capacity of the reservoir canals.

Although as regards first cost alone it appears that the larger plant and small reservoir should be used, other factors enter into the problem. With larger canals the lift would be less, due to the flatter surface slope of the water flowing to the plant. When pumping from the larger canal the service of the pumping plant would be less intermittent, thus saving considerable of the fuel necessary for firing up the plant. The rate of interest on the cost of the plant would be the same and the expense of clearing the canals of accumulated silt would be more or less independent of the size, at least within reasonable limits. In removing the run-off from a given storm the small plant would have to operate longer, thus increasing the labor charges. The proper weight to give each of these factors would depend on the local conditions in the district in question.

LOCATION, DESIGN, AND CONSTRUCTION OF PLANT.

Theoretically, the plant should be so located that the water in coming to it will travel the minimum length of reservoir canal. This condition will usually be met if the plant is placed in the center of the district and discharges through a leveed outfall canal to some bordering lake or bayou. In practice, however, the plants ordinarily are located on one side of the tract and on some navigable lake or bayou. This greatly facilitates the transportation of heavy machinery during the erection of the plant, as the ground usually is much too soft to allow the hauling of heavy loads. Fuel, also, can then be transported cheaply. If the tract has any considerable slope the logical location of the plant is in the lowest part. However, this part often is very soft, and to secure foundation it may be advisable to locate in some higher and more stable portion. As pointed out in the discussion of levees, there are frequent ridges of silt winding through these swamps, and often a plant can be located on one of these solid ridges. While it would be necessary to use a great many piles under the foundation in either case, the number can be reduced if the plant is located on a ridge.

The foundation under both the machinery and the building of a pumping plant should be of concrete, well supported by piling. A plan of the foundation under the plant at Gueydan already has been shown (fig. 10) and is a good illustration of a foundation in this character of soil. The foundation under the plant on the Des Allemands drainage district, already illustrated (fig. 8), also is a good one. It will be noted on both these plans that the foundation is surrounded by sheet piling and that under the center of the Des Allemands plant a line of sheet piling has been driven and extended into the concrete. In these soft soils such precautions are necessary. The engine and pump are usually mounted on the same block of concrete, so that any subsequent settlement can not throw them out of line.

While buildings to inclose the machinery should be durable and of fireproof construction, they are not called upon to protect the machinery and attendants from low winter temperatures. A frame of structural steel covered with heavy, corrugated, galvanized iron answers the purpose very well, although in one case a brick building has been erected. These buildings should be capable of resisting the action of the tropical hurricanes, for it is at such times that the need for the plant is greatest.

The selection and arrangement of machinery in centrifugal pumping plants have been discussed in detail in publications of the department.[1] While the local conditions considered in those publications are somewhat different from

[1] U. S. Dept. Agri., Dept. Bul. 304, contributed by Office of Public Roads and Rural Eng.; U. S. Dept. Agr., Office of Experiment Stations, Cir. 101.

those in southern Louisiana, the same principles are involved, and the same general features are to be considered.

The average lift of the drainage pumping plants is from 4 to 6 feet, with the total head ranging from 0 to 10 feet. Special attention should be given to the reduction to a minimum of all friction and velocity-head losses, as a poor arrangement of piping to the pumps may easily increase the total head 50 to 75 per cent. Plants have been inspected where the total head on pump was nearly double the useful lift. The cost of properly designed pipes is very little more than that of pipes which cause large losses.

The design of the pumps must be especially suited to low and variable lifts in order to give efficient service. The ordinary centrifugal pump designed for higher lifts is very inefficient when used on low-lift conditions. Sometimes it is advisable to design the pumps to run most efficiently at considerably less than the maximum capacity required of them when the demand is the heaviest. Thus nearly all the water can be pumped while running the pumps at the best possible capacity for efficiency, as the number of days per year that the plant will be called upon to operate at its maximum capacity are very few, averaging perhaps five. In this way a comparatively small and cheap plant can be installed and the maximum required capacity obtained by speeding up the pumps above their normal rate.

Various types of pumps have been examined in the plants inspected. The horizontal centrifugal pump and the horizontal screw pump are the only ones entirely suitable for drainage service of this nature. One large rotary pump was inspected, and while it was pumping water very efficiently, the minimum lift through which it could work was 10 feet, which was nearly twice the required lift. Such pumps are more expensive and require more expensive foundations than do centrifugal pumps.

It is advisable to install not less than two units in a plant. The low stages of water in the reservoir canals can then be handled properly, and a breakage of machinery would not render the plant inoperative. Owing to the fact that the soil on the average reclamation district will subside from 2 to 3 feet during the early years of reclamation, both the average and the maximum lift of the pumping plant will probably increase by that amount. Provision should be made for this increase of lift by having sufficient power for driving the pumps and by having the suction pipe of sufficient length.

On all pumps some means should be installed of indicating whether or not they are discharging at the proper rate under a given set of conditions. Vegetation growing in the reservoir canals will be carried through even a closely spaced screen in the suction basin and will lodge on the impellers; this will reduce the capacity materially even if its presence can not be detected by the most careful operator. Tests have been made on plants where the capacity was reduced as much as 30 per cent from this cause. Where the pump has two suction pipes, vacuum gages installed on the pipes close to the pump will indicate by a sudden change in pressure that débris has become entangled in the impeller. An instrument known as a rate-of-flow meter, reading in thousands of gallons per minute, has been devised for connecting to the discharge pipes; this will indicate at all times the amount of water passing through the pumps. If the amount of water indicated by this meter is less than it should be for a certain lift and speed of rotation of the impeller, the pump should be cleared of débris at once. After pumps are installed a thorough test should be made to see whether or not they come up to the guaranteed efficiency and to determine the proper speed at which to run them to obtain the best efficiency.

All the older pumping plants in this section were driven by steam engines; the types of engine varied from the cheapest slide-valve to the most expensive type

of poppet valve using super-heated steam. Within the last three years a number of internal-combustion engines have been installed. These, too, vary in character from the ordinary gasoline-burning engine to those which burn the heavy crude oils. One plant close to New Orleans uses electric power. Both the internal-combustion engines and the electric motors have great advantages over the steam engines when used on intermittent service. There are considerable losses, both of fuel and labor, in starting a steam plant, while the other types can be started without much loss of either. Although the total period of operation of the average drainage pumping plant is about 20 days of 24 hours each per year, the plant probably will operate on as many as 90 different days. This means that the average period of operation for each time it is fired up will be very short, perhaps less than 6 hours; therefore a large percentage of the fuel burned will be used in getting started. Owing to the familiarity of ordinary workmen with steam engines, and to the simplicity of such engines, they still are very popular as a source of power for driving the pumps. On the other hand, the great saving in labor and fuel obtained by the use of engines burning crude oil has resulted in all the newer plants being driven by oil engines. The depreciation of the steam plant, particularly of the boiler because of bad feed water and the rapid corrosion of sheet metal in this climate, is much greater in such intermittent service than is the depreciation of internal-combustion engines.

Cost of Pumping Plants.

The cost of drainage-pumping plants, per indicated horsepower, varies widely according to type of machinery, expense of transportation of machinery to site of plant, character of foundation, and difficulty of erection. The last three items will vary greatly according to local conditions. An accompanying diagram (fig. 16) shows comparative approximate costs of single-unit centrifugal pumping plants erected complete, inclusive of foundations, but exclusive of buildings, intake, discharge canals, or flume. These costs are based on estimates for work in Louisiana and Texas, and the diagram is published by courtesy of H. L. Hutson, New Orleans, La. These figures are approximate, but are on the safe side; that is, they take into consideration construction under unusual difficulties. In making up these costs it was assumed that the effect of the three items mentioned as varying according to local conditions would be a constant percentage of the cost of the plant. It is obvious that this diagram should not be used in attempting to determine accurately the cost of a drainage plant; its chief usefulness is in showing the relative cost of the various types of machinery, for deciding upon the most economical size of unit to be used in large plants, and for making approximate estimates of the total cost of plants.

In making the diagram, the cost of the plant has been divided into the cost of the "water end" (pump, pump foundation, and piping), and the cost of the "steam end" (engines, boilers, and their foundations and auxiliaries). The cost of the water end is given in terms of gallons per minute of rated capacity, and that of the steam end in terms of indicated horsepower. Owing to the variation in costs it is necessary to use zones instead of lines to indicate them.

The zone marked "steam end, compound condensing Corliss or 4-valve engine" includes the cost of this type of engine and water-tube boilers. The zone marked "Compound condensing slide valve" includes the cost of this type of engine and either water tube or return tubular boilers, according to the size of the plant. The zone marked "Simple slide-valve noncondensing" includes the cost of this type of engine and horizontal return tubular boilers. It will be noted that for the higher class engines the cost is not indicated below about

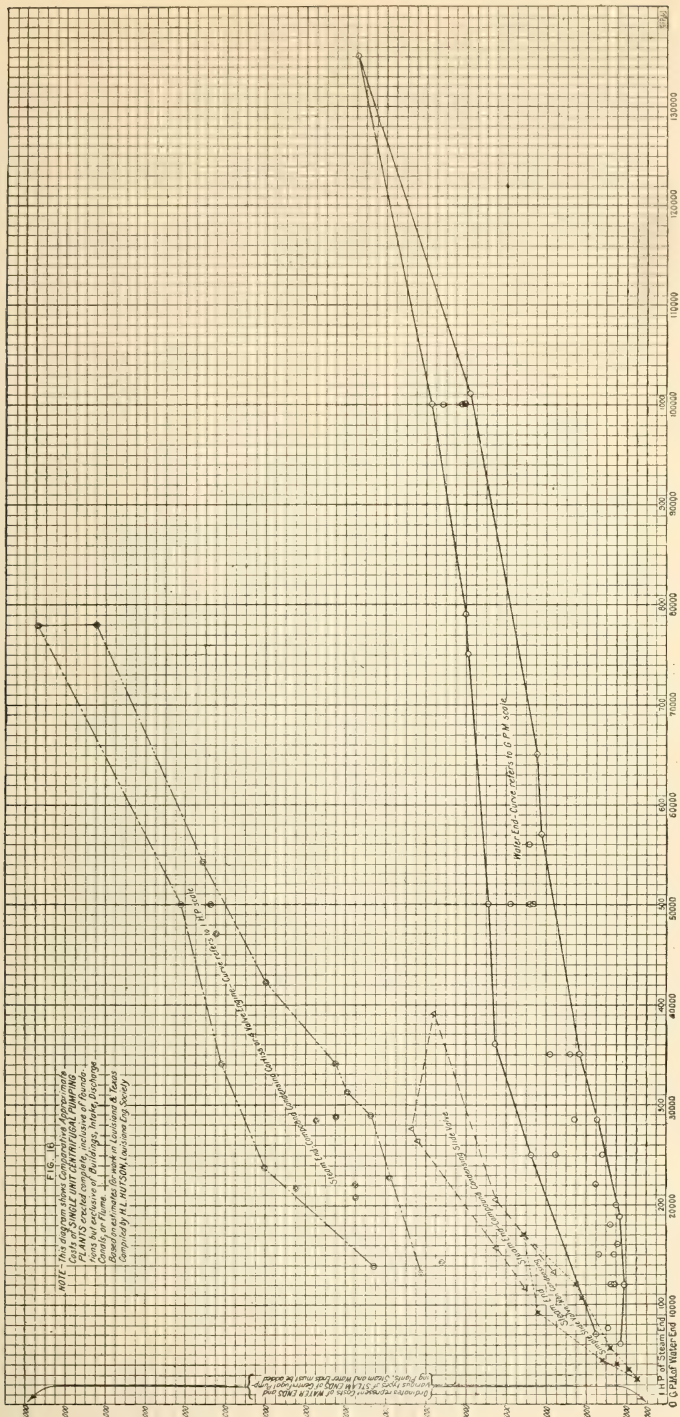


FIG. 16
NOTE - This diagram shows Comparative Approximate Cost of Water Lifted per Hour in Various PLANTS erected complete, inclusive of Boilers, Pumps but exclusive of Buildings, Intake, Discharge Canals or Flumes
Based on Plants Constructed in Louisiana & Texas
Compiled by H.L. HUDSON, Louisiana Eng. Society
Water End Curve refers to G.P.M. scale.
Steam Plants
Gas Engine Plants
Oil Engine Plants
Electric Plants
Windmill Plants
Cost of Complete Plant including Pumps and Motive Power
Cost of Pumps, Motors and Motive Power
Cost of Pumps
Cost of Motive Power
Cost of Motors
Cost of Pumps and Motors
Cost of Motive Power and Motors
Cost of Motive Power and Pumps
Cost of Pumps, Motors and Motive Power

100 horsepower, as engines of this class can not be purchased in smaller sizes than 75 or 100 horsepower.

In estimating the cost of a plant the following steps are necessary. With a given capacity of plant in gallons per minute, estimate the cost of the water end by use of the water-end zone. In order to get the cost of the steam end the indicated horsepower must be calculated first. First the water horsepower is determined, knowing the capacity and lift of the plant; then this is divided by the combined efficiency of the engine, transmission, pump, and piping, which will give the indicated horsepower. By using the various zones of cost of different types of engines, the cost of the steam end can be determined. Then by combining the cost of water end and steam end the total cost of plant will be determined.

TABLE II.—*Descriptions of equipment and unit prices of operating expense.*

District	Location.	Pumps.				Excess lift (actual exceeds effective).	Transmission of power.	Engines.	
		Number and kind.	Size.	Capacity.				Number and kind.	Size.
				Per second.	Per 24 hours.				
				Cu. ft.	*Inches.*	*Feet.*			
Smithport Plantation	Lockport [1]	1 square wooden-case centrifugal.	32 by 12 inch impeller.	30	1.10	2.0	Rope drive	1 slide-valve noncondensing.	11 by 12 inches.
		do	24 by 8 inch impeller				do	do	12 by 10 inches.
Willswood Plantation	Waggaman	1 square wooden-case centrifugal.	42 by 16 inch impeller.	153	1.40	5.0	Rope and bevel gear.	2 slide-valve noncondensing.	16 by 24 inches.
		1 rotary	7 feet wide			5.0	Rope drive	Automatic	16 by 24 inches.
		1 horizontal cast-iron centrifugal.	36-inch discharge			2.0	Direct connected	1 double slide-valve vertical.	14 by 14 inches.
Reclamation district No. 1	Poydras	1 horizontal cast-iron centrifugal.	do	100	.95	[2] 2.5	do	1 slide-valve noncondensing.	14 by 18 inches.
		do	24-inch discharge			[3] .6	do	do	10 by 14 inches.
Lafourche drainage district No. 6, subdistrict No. 1.	Des Allemands	2 horizontal cast-iron centrifugal.	do	59	.75	.3	do	2 slide-valve vertical.	12 by 12 inches.
Lafourche drainage district No. 12, subdistrict No. 3.	Raceland	do	30-inch discharge	109	1.15	.75	do	do	14 by 16 inches.
Gueydan drainage district, subdistricts Nos. 1 and 2.	Gueydan	do	54-inch discharge	394	1.25	.3	do	2 Corliss noncondensing.	16 by 36 inches.
New Orleans Lake Shore Land Co.	Ponchartrain Groves.	do	48-inch discharge	350		.6	Herringbone gear.	Electric motors	2 215-horsepower.
Jefferson drainage district No. 3	Lafitte	do	do	263	1.25	.4	Direct connected	2 Corliss noncondensing.	16 by 36 inches.
Lafourche drainage district No. 12, subdistrict No. 1.	Raceland	do	24-inch discharge	60	1.70	.4	do	2 40-horsepower oil-burning.	14½ by 21 inches.

[1] Large plant, on account of leaking levees.

[2] March, 1912, to August, 1913.

[3] Since August, 1913.

TABLE II.—*Descriptions of equipment and unit prices of operating expense.*—Continued.

District.	Location.	Efficiency of engine, pump, and piping at average effective lift.	Boilers.		Fuel.		Labor.		General condition of plant.
			Number and kind.	Size, (horsepower).	Kind.	Unit cost.	Wages.	Grade.	
		Per cent.							
Smithport Plantation	Lockport [1]	Not tested Low	1 return, tubular	100	Coal and oil [2]	$4 per ton; $1.15 per 42 gal.	$1.50 per day of operation.	Unskilled	Poor.
Willswood Plantation	Waggaman	12	2 water-tube	150 each	Oil	$0.80 to $1.70 per bbl. [3]	$3 per day of operation.	Good	Good.
		32	1 return, tubular.	80	do	do	$1.50 per day	Unskilled assistant.	
Reclamation district No. 1	Poydras	53	2 return, tubular.	80 each	Oil and coal	$0.90 per bbl	$1.80 per day	Good engineer	Do.
					Coal	$3.25 per ton	$1 per day	Fair fireman	
Lafourche drainage district No. 6, subdistrict No. 1.	Des Allemands	55	2 return, tubular.	60 each	Oil	$1.15 per bbl	$1.50 per day of operation.	Good	Do.
Lafourche drainage district No. 12, subdistrict No. 3.	Raceland	35	do	100 each	do	do	do	Unskilled	Fair.
Gueydan drainage district, subdistricts Nos. 1 and 2.	Gueydan	55	do	150 each	do	$0.80 to $1.25 per bbl.	$100 per month, 1912; $3 per day. [4]	Expert engineer	Good.
							$1.50 per day	Good fireman	
New Orleans Lake Shore Land Co.	Ponchartrain Groves.	50				[5]	do	Good	Do.
Jefferson drainage district No. 3	Lafitte	55	2 return, tubular.	150 each	Oil	$1.15 per bbl	$35 per month	Expert	Do.
Lafourche drainage district No. 12, subdistrict No. 1.	Raceland	40			do	$1.50 per bbl	$1.50 per day	Fair	Do.

[1] Large plant, on account of leaking levee.
[2] Fuel changed from coal to oil, September, 1912.
[3] In 1912, cost of fuel oil rose from $0.80 to $1.70 per barrel.
[4] About January, 1913, the engineer was changed from a monthly wage to a rate per day when operating plant.
[5] 1 cent per kilowatt hour plus $230 per month fixed charge.

TABLE III.—*Costs and conditions of operation.*

District.	Area.	Year.	Rainfall.	Run-off.	Average effective lift.	A.F.F.[1]	Cost.							Number of days on which plant operated.	Number of times boilers were fired up.	Number of 24-hour days per year at full capacity.	Hours at full capacity per fire-up.	Longest period of continuous operation.	Number of times plant was run continuously more than following number of days.					
							Fuel.	Labor.	Repairs and incidentals.	Total.	Per acre.	Per A. F. F.[1] Total.	Per A. F. F.[1] Fuel.						1	2	3	4	6	10
	Acres.		*Inches.*	*Inches.*	*Feet.*													*Days.*						
Smithport Plantation	647	[2] 1911	57.52	33.35	5.2	9,400	$667	$351	$150	$1,168	$1.80	$0.125	$0.071	115	103	33.0	7.7	2.0	8	1	0	0	0	0
	647	[3] 1912	52.23	40.80	5.5	12,190	795	342	170	1,307	2.02	.108	.066	108	77	49.5	12.9	4.3	12	5	3	1	0	0
	647	1913	60.01	37.77	5.8	11,840	780	215	35	1,030	1.60	.087	.066	86	68	34.2	12.0	3.8	10	3	1	0	0	0
Willswood Plantation.	2,400	[4] 1909	43.32	16.33	5.0	16,330	936	600	230	1,766	.73	.108	.057	45	39	20.0	7.3	2.5	3	1	0	0	0	0
	2,400	1910	43.08	11.58	5.0	11,580	616	500	180	1,296	.54	.112	.053	45	41	8.4	4.9	.75	0	0	0	0	0	0
	2,600	1911	52.32	23.42	5.0	25,290	1,267	753	300	2,320	.89	.092	.050	69	61	19.2	7.6	3.5	5	1	1	0	0	0
	2,600	[5] 1912	48.22	34.42	5.0	37,290	2,676	765	514	3,955	1.52	.106	.072	81	63	35.0	8.9	4.0	10	4	1	1	0	0
	2,600	1913	51.52	27.08	5.0	30,180	2,412	848	457	3,717	1.43	.123	.080	68	60	17.5	7.0	2.0	6	2	0	0	0	0
	2,600	1914	42.25	15.05	5.0	16,320	1,210	426	464	2,100	.81	.129	.074	41	39	9.7	6.0	2.2	2	1	0	0	0	0
	2,600	1915	5.05	34.24	5.0	37,100	3,030	751	922	4,703	1.80	.127	.082	63	49	24.5	12.0	4.77	8	3	3	2	0	0
Reclamation district No. 1 Poydras.	2,500	[6] 1912	70.52	28.28	2.1	12,420	1,098	640	244	1,982	.79	.160	.088	114	77	41.8	10.5	14.0	12	9	7	4	1	1
	2,500	1913	63.45	38.82	4.5	36,580	2,314	1,261	347	3,922	1.57	.107	.063	155	131	46.5	8.5	6.5	4	3	2	1	1	0
	2,500	1914	47.70	16.46	5.2	18,320	743	764	408	1,915	.77	.105	.041	73	71	17.8	6.0	2.0	2	1	0	0	0	0
	2,500	[7] 1915	36.14	16.21	5.2	17,572	755	582	180	1,517	.61	.086	.043	62	60	22.8	6.8	1.77	5	0	0	0	0	0
Lafourche drainage district No. 6, subdistrict No. 1.	1,880	1913	47.37	31.00	5.1	24,910	1,526	564	116	2,206	1.18	.089	.061	210	198	40.0	4.8	5.0	5	4	2	1	0	0
	1,880	1914	45.70	25.83	5.3	21,340	871	517	65	1,453	.77	.068	.041	178	159	35.3	5.3	4.8	8	5	2	1	0	0
	1,880	[7] 1915	28.41	21.94	5.4	18,745	1,160	331	25	1,516	.80	.081	.062	92	75	39.0	9.4	3.71	11	7	3	0	0	0
Lafourche drainage district No. 12, subdistrict No. 3.	2,250	1913	52.04	20.84	2.9	11,270	930	306	331	1,567	.70	.140	.082	90	90	15.5	4.1	.75	0	0	0	0	0	0
	2,250	1914	58.95	23.40	3.5	14,870	1,140	233	194	1,567	.70	.106	.077	78	71	18.7	6.3	1.60	3	0	0	0	0	0
	2,250	[7] 1915	33.07	11.61	4.2	9,087	1,115	112	265	1,492	.66	.164	.123	41	39	13.5	6.2	1.42	2	0	0	0	0	0

[1] Acre-feet of water lifted 1 foot.
[2] March, 1911, to February, 1912, inclusive.
[3] March to December, inclusive.
[4] June to December, inclusive.
[5] January to May and October to December, inclusive
[6] March 9 to December 31.
[7] January to September, inclusive.

TABLE III.—*Costs and conditions of operation*—Continued.

District.	Area.	Year.	Rainfall.	Run-off.	Average effective lift.	A. F. F.[1]	Cost.							Number of days on which plant operated.	Number of times boilers were fired up.	Number of 24-hour days per year at full capacity.	Hours at full capacity per fire-up.	Longest period of continuous operation.	Number of times plant was run continuously more than following number of days.					
							Fuel.	Labor.	Repairs and incidentals.	Total.	Per acre.	Per A. F. F.							1	2	3	4	6	10
												Total.	Fuel.											
	Acres.		*Inches.*	*Inches.*	*Feet.*													*Days.*						
Gueydon drainage district, subdistricts Nos. 1 and 2.	6,500	[2] 1912	41.71	37.26	3.6	75,200	$2,640	$1,225	$795	$4,660	$.72	$.062	$.035	196	185	40.0	4.1	4.0	6	3	2	1	0	0
	7,500	[3] 1913	77.61	65.86	5.0	194,000	6,013	1,321	631	7,965	1.06	.041	.031	214	173	53.0	7.4	19.54	13	5	2	1	1	1
	6,500	[4] 1914	59.78	39.86	5.1	109,350	.....	.....	.....	5,175	.79	.047	.....	166	162	28.0	4.1	5.2	7	1	1	1	0	0
	6,500	[4] 1915	49.77	24.21	5.2	68,644	1,833	1,180	867	3,880	.60	.056	.027	78	77	19.4	6.0	2.79	6	2	0	0	0	0
New Orleans Lake Shore Land Co.	6,040	[5] 1914	50.60	20.46	4.5	46,760	[6]3,932	.....	.....	5,650	.....	.121	.084	308	308	16.0	1.2	.6	0	0	0	0	0	0
	6,943	[7] 1915	36.80	20.33	5.2	61,496	[6]3,603	912	34	4,549	.65	.074	.059	172	.....	21.7	.....	2.15	3	2	0	0	0	0
Jefferson drainage district No. 3.	5,000	[8] 1913	49.60	28.42	5.1	59,970	2,565	692	480	3,737	.75	.062	.043	121	119	29.0	4.9	2.5	1	1	0	0	0	0
	5,000	[9] 1914	48.16	26.45	4.7	51,630	2,274	595	261	3,130	.63	.061	.044	104	97	18.3	4.5	2.9	5	1	0	0	0	0
	5,000	[7] 1915	44.61	18.18	5.1	38,578	1,600	700	350	2,650	.53	.069	.042	61	59	15.9	5.9	1.83	1	0	0	0	0	0
Lafourche drainage district No. 12, subdistrict No. 1.	835	[8] 1915	30.38	20.25	3.6	5,157	75	160	25	260	.31	.050	.014	41	40	15.9	9.0	1.0	1	0	0	0	0	0

[1] Acre-feet of water lifted 1 foot.
[2] March 17 to December 31. Area 5,600 to Aug. 23, 1912, then increased to 6,500.
[3] Area increased to 7,500 in July; decreased to 6,500 Dec. 31, 1913.
[4] Area 6,500 acres Dec. 1, 1915; 7,500 acres after Dec. 1, 1915.
[5] Average for year, electric plant.
[6] Electric power.
[7] February to December, inclusive.
[8] March 12 to December 31.
[9] January to September, inclusive.

Cost of Operation.

Records of operation have been kept for a number of pumping plants in drainage service in southern Louisiana. Not all of the plants included in these records are typical, neither have conditions been typical, but it is believed that it will be of service to include all the plants so that a comparison may be made of the saving in cost of operation that may be effected, first, by having good levees around the district; second, by properly installing efficient and suitable machinery; third, by operating the plant carefully.

The equipment of each pumping plant, as well as the kinds and costs of fuel and labor, are shown in Table II. Table III shows the costs of operation, including fuel, labor, and repairs; it also shows the conditions under which the plants were operated. For the purpose of comparing the costs for the various plants a unit has been chosen which eliminates any effect of differences in the amounts of water pumped and lifts of the pumps; this unit is the cost of lifting 1 acre-foot of water 1 foot. Of course the pumps with the higher average lifts worked at a relatively greater efficiency. It should be noted that Table III shows average effective lift rather than the actual lift, the former being the difference between the elevation of the water surface from which water is being pumped and that of the water surface where the pumps discharge. The cost of pumping likewise is expressed in the cost of lifting 1 acre-foot of water 1 effective foot.

As an example of the large amount of pumping that may be caused by seepage through poorly designed or built levees, the results for 1912 and 1913 on the Smithport tract and those for 1913 for the Gueydan district should be compared with the results for 1913 and 1914 from subdistrict No. 3 at Raceland. The amount of water pumped on the latter district was scarcely half that pumped on the other two districts, although the amount of rainfall was not far different.

The cost figures given in the table must be compared with due regard to conditions of operation and to the average lift of the pumps. The effect of a change of lift of a pump is shown in the figures for nearly all the plants, but especially in those for reclamation district No. 1 at Poydras, subdistrict No. 1 at Des Allemands, and subdistrict No. 3 at Raceland. On certain other of the plants the fact that an increase in lift has not caused a decrease in unit cost is due to the increase in fuel cost.

As all of the Corliss engine plants are on large districts, a condition that tends to a relatively large reduction in the labor charge per unit of water lifted out of the district, it will be advisable to disregard the item of labor and make the comparison on cost of fuel alone; this will largely eliminate the effect of the size of the district. With the exception of the year 1914, the cost in fuel of lifting an acre-foot of water 1 foot was much less for the Corliss engine plants than for those using slide-valve engines. The plants in subdistrict No. 1 at Gueydan and Jefferson drainage district No. 3 are similar in equipment, except that the pumps in the Gueydan district are larger. It will be noted that the cost of fuel used per unit of water lifted (Table III) is less for the Gueydan district than for the other. The lifts and the lengths of run per fire up are about the same, while the unit cost of fuel (Table II) is lower for the Jefferson plant. This difference in cost of operation might be due partly to the fact that these two plants have the same sized engines, which results in the engines in the Gueydan plant working at about their proper capacity, while those in the Jefferson plant are working at a considerable underload. No doubt, however, the greater part of the difference is in the care with which the oil has been fired under the boilers.

For the plants having slide-valve engines, a comparison of the costs of fuel for lifting an acre-foot of water 1 foot will show that the effect of the highest average lift and the longest run per fire up for the year 1913, which occurred in the Smithport plant, has served to make the latter plant compare favorably with the other slide-valve plants, although it is by far the poorest plant of the lot. On the other hand, the effect of the lowest lift and the shortest run per fire up for the year 1913, which occurred in the Raceland plant, has served to make it the most expensive plant per acre-foot of water lifted 1 foot, although the Raceland plant is the equal of any of the other slide-valve plants. The efficiency of the pumps in the plant at Poydras was increased considerably by the changes made in pipes and impellers in 1913.

The only plant operated by electricity shows a considerably higher cost for power in 1914 for lifting an acre-foot of water 1 foot than do most of the steam plants. However, it will be noted that the amount of pumping was small, and as the relatively large monthly charge for current is a constant, whether the pumps are operated or not, on years of small pumping the unit cost in this plant will be high. In the first nine months of 1915 about the same quantity of water was pumped as in the whole of 1914, but the fixed charge was proportionately less. Therefore the unit cost was much less in 1915 than in 1914.

While a number of plants were in operation in which the pumps were driven by oil-burning engines, the cost data are available only for subdistrict No. 1, Raceland. However, the small unit cost for lifting an acre-foot of water 1 foot is a striking feature of this plant. The unit cost for labor is high on account of the small area of this district. The total charge for labor on a plant of this kind need not be much more for a plant large enough to drain an area several times greater.

The amounts of rainfall and run-off on the districts given in the foregoing tables are not all typical, and an average of them would not give a figure suitable for general application. From these a selection has been made of the typical figures; an average of them is as follows: Rainfall, 48.61 inches; run-off, 21.56 inches; per cent of rainfall appearing as run-off, 44.4. The mean annual rainfall for this section is about 56 inches, so that the amount pumped under average conditions would be a depth of 24.8 inches per year. The average lift for plants in this section would not be far from 5 feet. Following are the average results from the various plants under actual conditions of operation; it includes only those figures which are known to be typical:

Average results from various plants.

Kind of plant.	Total cost of operation per acre-foot foot.	Cost of fuel per acre-foot foot.	Total cost of lifting 2 acre-feet 5 feet.
Steam slide-valve engine	$0.075	$0.050	$0.75
Steam Corliss-valve engine	.060	.035	.60
Oil engine	.040	.015	.40
Electric motor	.097	[1].072	.97

[1] Cost of power.

Since the average amount of water to be removed from drainage districts in this section is about 24 inches per year, the average cost, per acre per year, of operation of drainage pumping plants will be about as shown in the last column of the above table.

Not all the pumping plants have kept careful and complete records of their operation. Without such records it is impossible to know whether or not the plant is being run economically or to ascertain sources of waste. From the standpoint of the owners of the land such records are as essential as are the accounts of any business concern to its proprietors. These records are essential also to progress in the matter of design and construction, not only of the pumping plant, but of the other drainage improvements. If the canal system is adequate or the levee system subject to seepage, careful records of operation will show that further improvement is necessary. The proof of the value of any set of improvements is the service rendered, and unless records are kept it will not be possible to judge of the serviceability of such improvements.

In the past, owing to a lack of records of actual operating conditions, the capacity of the pumping plant and the character of the machinery have varied widely on the different districts. The data herein published as to amount and cost of pumping should enable those in charge of the design and operation of such improvements to judge better of the requirements. These records will become of much greater value if they are continued over a long term of years and if they are extended to include all districts drained by pumps.

The following form is recommended as one including the essential features of daily operations.

FORM FOR DAILY PUMPING RECORDS.

(Date)_____ 191____.

Hour.	Suction gage.	Discharge gage.	Speed of pumps.			Start pump.	Stop pump.	Flow meter. Gallons per minute.		
			No. 1.	No. 2.	No. 3.			No. 1.	No. 2.	No. 3.

One page should be used for each day. The gages in the reservoir and the discharge canal should be read before starting and again about one-half hour after starting. If practicable, all items should be entered once each hour. Other items that might affect the operation of the plant, such as improper canals or seepage through levees, should be noted.

Expenses of operation should be kept carefully and classified under the following headings: Fuel, labor, supplies, repairs, and superintendence. The records should be kept in such a form that the totals for each month and year can be determined. The cost per acre per year can thus be obtained, but to determine the cost of removing a certain unit of water the capacity of the pumps at the various speeds and lifts should be determined by testing. The above form provides for such data that the amount of water pumped can be

calculated. If such records are kept on each district they will show whether the pumping plant is being operated properly, and they will enable future drainage improvements to be designed much more intelligently than heretofore.

UTILIZATION OF LAND.

In general, the water is lowered as rapidly as possible on these marshlands when they are first reclaimed. The lateral ditches are then cut and complete drainage of the soil obtained. Owing to the soft, spongy nature of the soil, it can not be cultivated immediately after drainage with ordinary farm animals and machinery. The work of reducing the soil to suitable condition for ordinary cultural methods belongs properly to the work of reclamation. As already mentioned under the detailed descriptions of the typical districts, the first cultivation of the land must be done with special machinery. After the land is cleared of grass the extra large disk plow has been found the best means of plowing it. These plows must be mounted on wheels of considerably more than the usual width. The tractor which draws these plows is the principal factor in doing the work successfully. Plate I, figure 1, shows a type of tractor which has been very successful. It is the type which was used almost exclusively on the plowing of the New Orleans Lakeshore Land Co. tract. As shown by the picture, the apron wheels are wide and exert only a small unit pressure on the soil, at the same time affording a very large tractive area for pulling. The body of the tractor is set well above the surface of the ground. This is an essential feature, for when the apron wheels sink into the ground, if the clearance of the body of the tractor is small the framework will rest on the ground, and further progress will be checked. Following the first plowing it is customary to pulverize the ground thoroughly with a double-disk harrow drawn by the same type of tractor. With ordinary weather conditions it is usually possible to place ordinary farm animals on such soils two or three months after they have received the above-described treatment. Where the land is especially soft it probably will be necessary to equip the feet of the animals with "bog shoes."

The first plowing of the land should not be attempted until it is fairly well drained. Lands that are especially soft may have to be drained for several months before they can be plowed, although much will depend on the time of year and the amount and distribution of the rainfall. As much progress is made in cultivating these raw lands in one dry year as in two wet years. The transforming of the dry, raw land to a cultivated field has been one of the most unsatisfactory and expensive operations in the reclamation of these lands. This has been due principally to the use of improper machinery and the attempt to plow the land before it was sufficiently drained. However, methods have advanced so far, and the special machinery necessary for the work has been so well worked out, that it is possible to make this transformation with reasonable expense.

Usually the first crop planted is corn. Frequently this is planted by corn planters drawn by the above-described tractors. In the average district it is possible to cultivate the first crop by ordinary methods. Following the first crop of corn a wide variety of crops have been grown successfully. The heavy percentage of vegetable material makes it easy to maintain a mulch of dry soil on the surface, and by proper management of the pumping plant the stage of water in the canals and ditches can be so controlled that the water is not reduced too great a distance below the surface.

FINANCIAL.

In its original state much of the prairie land is worthless, its only usefulness being in that it serves as a trapping and hunting ground. Its present market value is due to possibilities of reclamation rather than to any present usefulness and is more or less speculative. The value of the land varies according to the completeness and permanence of the drainage improvements, as well as according to its original character. A wide variation exists in the quality of the improvements, especially in the pumping-plant equipment. The cost per acre of reclaiming the various districts depends on natural conditions, the completeness of reclamation, and the character of the drainage improvements. The usual variation in the cost of such reclamation is from $30 to $45 per acre.

SUCCESS OF DRAINAGE.

The drainage of these lands has been uniformly successful, and from the drainage engineer's standpoint the work is now well past the experimental stage. Where successful drainage has not been attained it has been due to insufficient and poorly constructed improvements rather than to inherent and insurmountable difficulties. On some of the districts the improvements have been installed without competent engineering advice and services, and while successful drainage has been secured in some such cases, it was not secured with the greatest economy. The earlier faults were due principally to attempts to drain the land too cheaply. This has been demonstrated to be false economy, and the present practice is almost uniformly of such a grade as will ultimately result in the complete drainage of the lands of this section.

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